In the Name of God

Journal of
Information Systems & Telecommunication
Vol. 5, No. 4, October-December 2017, Serial Number 20

Research Institute for Information and Communication Technology
Iranian Association of Information and Communication Technology

Affiliated to: Academic Center for Education, Culture and Research (ACECR)

Print ISSN: 2322-1437
Online ISSN: 2345-2773
Publication License: 91/13216

Editorial Office Address: No.5, Saeedi Alley, Kalej Intersection., Enghelab Ave., Tehran, Iran,
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This Journal is published under scientific support of
Advanced Information Systems (AIS) Research Group and
Digital & Signal Processing Research Group, ICTRC

Acknowledgement

JIST Editorial-Board would like to gratefully appreciate the following distinguished referees for spending their valuable time and expertise in reviewing the manuscripts and their constructive suggestions, which had a great impact on the enhancement of this issue of the JIST Journal.

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Design and Implementation of an Ultra-Wide Band, High Precision, and Low Noise Frequency Synthesizer

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Received: 22/Jul/2017 Revised: 16/Sep/2017 Accepted: 24/Dec/2017

Abstract

This paper presents system-level design and implementation of an ultra-wide tunable, high precision, fast locking, low phase noise, and low power portable fractional-N frequency synthesizer. The output frequency of the proposed design is ranged from 54 MHz to 6.8 GHz. The VCO cores cover frequencies from 3.4 GHz to 6.8 GHz. The programmable output dividers allow generation of the lower frequencies. The output power is tunable between -4dBm and +5dBm. It can generate a wide range, high precision, and linear frequency sweep. The sweep rate, frequency step, and frequency range are tunable. The new frequency tuning algorithm, named Yas algorithm, is proposed to improve frequency precision of the synthesizer. To demonstrate the efficiency of the Yas algorithm, the results of MATLAB simulations and experimental measurements are presented. The output phase noise is -95.55 dBc/Hz at 1 KHz offset from 3 GHz. The experimental measurement results demonstrate that the implemented frequency synthesizer can be used for applications, such as oscillator of spectrum analyzer, automatic test equipment, FMCW radars, high-performance clock source for high speed data converter, satellite communications, and measurement systems.

Keywords: Frequency Synthesizer; Wide Band; High Precision; Low Power; Phase-locked Loop (PLL).

1. Introduction

Frequency synthesizer is one of the most vital constituting blocks in any radio frequency systems. A well-designed frequency synthesizer system should meet requirements of wide output frequency range, high precision, low phase noise, and fast lock time. Phase-Locked Loop (PLL) based frequency synthesizers are the most popular architecture of synthesizers. The general architecture and operation theory of the PLL based frequency synthesizers are discussed in literatures [1-4]. Fractional-N frequency synthesizers support fractional N counter values, so they allow better performance, higher resolution and lower phase noise. The delta-sigma PLL reduces spurs by using digital techniques. This paper introduces system-level design and implementation of a wide band and high precision frequency synthesizer system. Conventional wideband frequency synthesizers have complex architectures, such as multiple PLL loops, each of which covers a specified band, to increase the output frequency range [5]. The proposed frequency synthesizer uses only a single delta-sigma fractional-N PLL to enhance loop stability and reduce lock time. Increasing the tuning gain of voltage controlled oscillator degrades PLL phase noise, considerably. This issue can be solved by employing overlapped tuning sub-band voltage controlled oscillator, which covers the desired frequency range [6]. A proper VCO band selection algorithm must be employed to select the optimum sub-band of VCO for the desired channel frequency [7].

The PLL of the proposed frequency synthesizer is controlled digitally by microcontroller with an SPI interface. Therefore, the output frequency will be tuned digitally without changing the reference frequency or sweeping tuning voltage of the voltage controlled oscillator directly.

Speed of locking is another important feature of the frequency synthesizer. It consists of calibration time plus analog settling time. Some methods of decreasing the lock time are discussed in literatures [8,9]. The loop bandwidth and phase margin of the loop filter affect the PLL lock time precision and the spurious level. Therefore, different techniques are discussed to find a best optimal solution for the design of the loop filer in [10]. The lock detection circuit indicates whether the PLL is in the lock mode or not. In this paper, designing the loop filter and the analog lock detection circuit are discussed.

One of the critical challenges in the design and implementation of the frequency synthesizer is proper output frequency tuning. The algorithm presented in [13] is not capable of providing a high precise frequency. In this paper a new frequency tuning algorithm is presented. The results of MATLAB simulations and experimental measurements are quoted to confirm the validity and better performance of the proposed algorithm.

Temperature can affect power distribution, signal integrity, and timing signals, which reduce reliability,

* Corresponding Author

safety, and electrical performance of the system. Moreover, copper's impedance can change by temperature [17]. The weak points in thermal or mechanical design, overstressed components, and low cooling efficiency can be identified by performing thermal analysis in design phase [18]. In order to improve reliability, performance, and stress of the designed system, thermal analyses are performed by using HyperLynx Thermal (Pads) software. Then, the optimized thermal printed circuit board of the system is designed.

The organization of this paper is as follows. The system-level design of the proposed frequency synthesizer is discussed in Section II. The simulation results are described in Section III. The implementation and experimental results of the proposed frequency synthesizer are presented in Section IV. Finally, Section V is the summary of this work.

2. Proposed Frequency Synthesizer: The System Level Design

The proposed frequency synthesizer is composed of two sections including the RF, the controller, and power supply sections. Fig. 1 illustrates the block diagram of the proposed frequency synthesizer.

2.1 RF Section

The RF section consists of a reference input, a fast phase frequency detector, a charge pump, a low pass loop filter, a voltage controlled oscillator, a lock detector, an auto voltage controlled oscillator band selection, an output power controller, and an output stage frequency divider. The noise of the reference input signal affects the output noise. The input signal noise scales at output, so it can be the dominant noise source. Therefore, the low noise reference oscillator must be chosen [19].

The reference input is used for locking the PLL and VCO calibration. Any spur, drift, phase noise, and instability at the output of the reference are the main sources to degrade resolution and precision of the frequency synthesizer. Therefore, the high precision and stable reference input is required.

For the best performance of the frequency synthesizer, the frequency of the phase detector should be maximized. The frequency of the phase detector is tuned by the R counter, frequency doubler, and frequency divider values.

The output frequency of VCO is divided by the factor of N and is fed to the phase frequency detector. The fast phase frequency detector and charge pump, outputs a correction current, which is proportional to the phase difference between the feedback and reference signals. The correction current is converted to the tuning voltage of VCO by the loop filter.

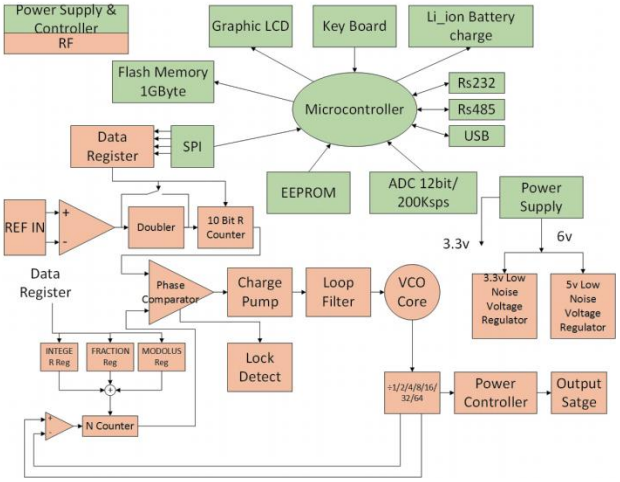

Fig. 1. Proposed frequency synthesizer block diagram

In our design, the reference frequency of the phase frequency detector is fixed at 78.125MHz. The proposed frequency synthesizer system contains 156.25MHz differential Temperature Compensated Crystal Oscillator (TCXO). The input reference of the system is differential, therefore the input reference traces are designed with the same length, shape, width, and distance to the ground.

The mentioned frequency synthesizer has four voltage controlled oscillator cores and overall 1024 voltage controlled oscillator sub bands, which cover the frequency range from 3400 MHz to 6800 MHz. The lower output frequencies can be achieved by the programmable frequency divider. The frequency divider ratio can be set between 1 to 1023 values. The voltage controlled oscillator sensitivity is 15MHz/V. The tuning range is 0 V to 5 V. whenever the output frequency is updated, the appropriate voltage controlled oscillator and its sub band are selected automatically by the auto calibration algorithm.

The RF frequency differential outputs of the frequency synthesizer are connected to the differential pair transistors. The RF output power is adjusted by tail current of the differential pair. The output frequency can be set to four power levels including +5dBm, +2dBm, -1dBm, and -4dBm. The differential outputs are sensitive to impedance mismatch; therefore, they are connected to equal load impedance through 50 ohm traces, which is connected to SMA connectors. The trace width calculation and design of the differential output transmission lines are performed in Advanced Design System for Rogers 4003 substrate with 10mil height for the frequencies between 54MHz to 6800MHz. The structure of the designed differential output pairs are symmetry.

Loop filter is another challenge of the system-level design and implementing the frequency synthesizer. The loop bandwidth and phase margin affect stability, precision, lock time, and phase noise of the frequency synthesizer. The loop bandwidth should be less than the reference frequency by a factor of at least 10. The best phase noise performance can be achieved, if the loop bandwidth and loop gain constant of the designed filter are optimum [10]. The loop gain is determined due to

voltage controlled oscillator gain and charge pump gain. Also the order of the loop filter should be one greater than the order of the delta-sigma modulator. For lowest RMS phase noise with the 900uA charge pump current, the loop filter is designed by using ADIsim PLL4 software. The parameters of the designed passive third order loop filter are summarized in Table 1. Fig. 2 shows the topology of the designed third-order passive loop filter.

Table 1. Parameters of the designed loop filter

Parameters	Value
Loop Bandwidth	39.1KHz
Phase Margin	45°
Zero Location	13.9KHz
Pole Location	109KHz
Last Pole Location	391KHz
C_1	3.90nF
R_1	215Ω
C_2	53.1nF
R_2	439Ω
C_3	1.77nF

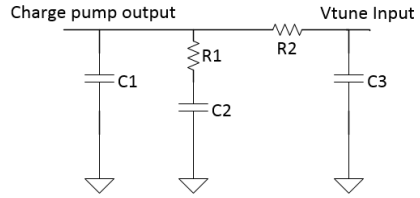

Fig. 2. The topology of designed third-order passive loop filter

Lock detection circuit checks whether the phase difference of feedback and reference signals are equalized or not. The proposed frequency synthesizer has analog and digital lock detectors. The analytical calculations for analog and digital lock detectors are discussed in [11-12].

Analog lock detect pin is an open drain output of PLL chip. Fig. 3 illustrates off-chip analog lock detection circuit. When the analog lock detect output is in high logic level, capacitor C_1 is charged by R_2C_1 time constant. When it is in low logic level, capacitor C_1 is discharged byR_1C_1 time constant. In order to achieve 1us lock detection with 78.125 MHz reference phase frequency detector, the analog lock detect circuit is designed by using ADIsim PLL4 software. The components values of the designed analog lock detect circuit are summarized in Table 2.

Table 2. the components values of the designed analog lock detection circuit

Component	Value
R_1	3 KΩ
R_2	9.41 KΩ
C_1	4.45 nF

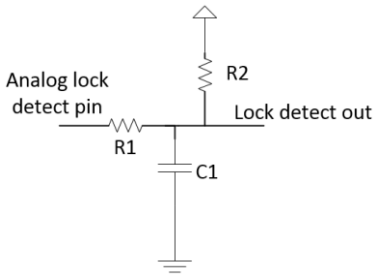

Fig. 3. Analog lock detection circuit

2.2 Controller and Power Supply Sections

The controller section consists of a microprocessor, communication ports, a 1GB internal flash memory, graphic LCD, keyboard, and EEPROM. The frequency synthesizer is designed to communicate with other systems through RS232, RS485, and USB ports. The system is supposed to store and load data in a 1GB internal flash memory. The system settings are stored into the internal flash memory and are loaded at the start up.

The controller section controls the PLL digitally by the SPI interface. The value of N counter of the fractional-N PLL is derived from (1), [13].

$$N = \frac{RF_{out}}{f_{PFD}} \quad (1)$$

The fractional-*N* values are achieved by switching *N* counter value between integer values such that the average value is the desired fraction. The sequence of the *N* counter value may influence the precision of the frequency synthesizer. The *N* counter value varies between 23 and 65535, depending on the desired output frequency. If the value of *N* counter is less than 75, the dual modulus pre-scaler is set to 8/9; otherwise, it is set to 4/5.The *N* counter value of frequency synthesizer is obtained from (2), [13]

$$N = INT + \frac{FRAC1+\frac{FRAC2}{MOD2}}{MOD1} \quad (2)$$

where *N*, *INT*, *FRAC1*, *MOD1*, *FRAC2*, and *MOD2* are *N* counter, 16-bit integer, 24-bit numerator of the primary modulus, 24-bit primary modulus, 14-bit numerator of the auxiliary modulus, and 14-bit auxiliary fractional modulus values, respectively.

The *INT*, *FRAC1*, *FRAC2*, *MOD1* and *MOD2* values make it possible to generate output frequencies that are spaced by fractions of the phase frequency detector frequency. The proper calculation of the *N* value results in a very fine frequency resolution with no residual frequency error. Analog Device presents a calculation algorithm, which set *INT*, *FRAC1*, *FRAC2*, *MOD1*, and *MOD2* values. In order to increase the frequency precision, a new frequency tuning algorithm, named Yas algorithm, is proposed. **Error! Reference source not found.** illustrates flowchart of the conventional and Yas frequency tuning algorithms.

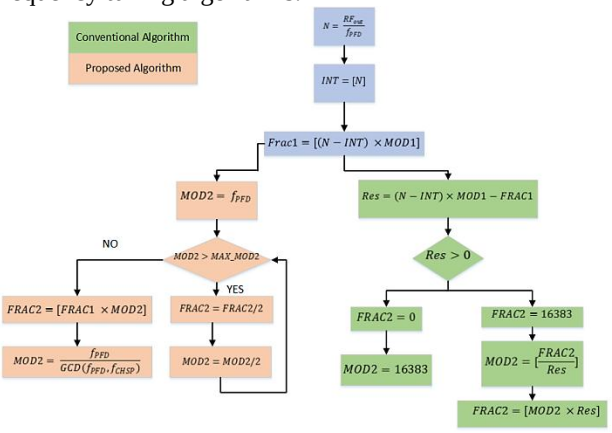

Fig. 4. Flowchart of the conventional and proposed frequency tuning algorithms [13]

3. Simulation Results

In order to realize and solve potential problems in the design phase and avoid costly overdesign or failure, time domain, frequency domain, and analytical simulation are performed. The proposed system is simulated using ADIsim PLL4 software to determine the phase noise and lock time. Moreover, the Yas and conventional frequency tuning algorithms are implemented in MATLAB.

3.1 Phase Noise Measurement

Phase noise is one of the critical features of the frequency synthesizer, because it reduces quality of the signal. The term phase noise describes the phase variations of the signal and the signal spectrum is no longer a discrete line. The total noise of the proposed system consists of the loop filter, chip, reference signal, and VCO noises. Fig. 5 shows the simulated phase noise versus offset frequency from the 3GHz output frequency. The phase noise at 1 KHz offset of the 3GHz is obtained as -93dBc/Hz.

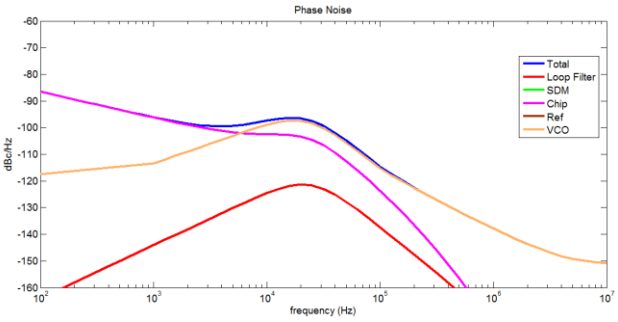

Fig. 5. Simulated phase noise of the proposed frequency synthesizer against offset frequency from 3GHz output frequency

3.2 Thermal Analysis

Thermal analyses are performed for printed circuit board of the RF section, which has higher thermal sensitivity. Testing is performed under the worst environment conditions in closed rack. Fig. 6 and Fig. 7 show temperature and temperature gradient of the RF PCB respectively.

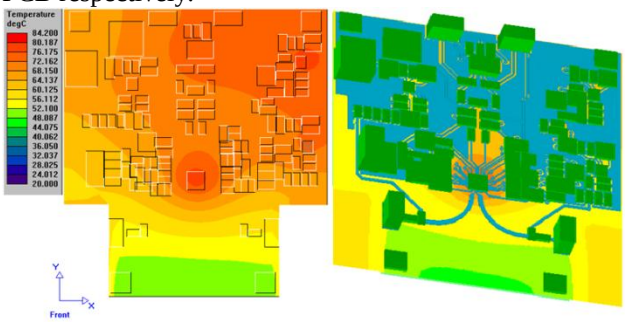

Fig. 6. Temprature analysis of the RF PCB

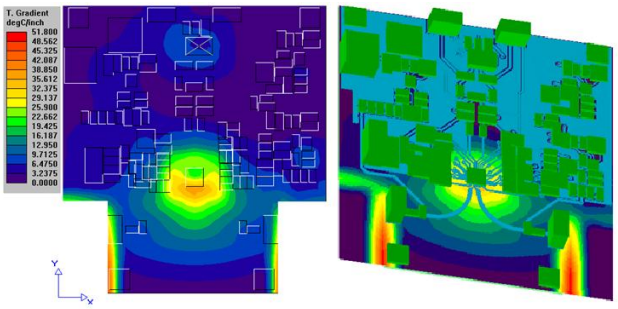

Fig. 7. Temprature gradient analysis of the RF PCB

The temperature and temperature gradient of the critical components, such as reference signal, VCO, loop filter, and PLL are high. They affect stability, reliability, signal integrity, and electrical performance; therefore, the layout must be improved.

In the new layout, the goal is to reduce temperature and temperature gradient of the mentioned critical parts. Component placement affects thermal and electrical performance of the system. Closer component placement and shorter connections improve signal integrity, but result in higher power density and higher temperature gradient locally. In order to improve thermal performance of the system, the high power components are placed as the near edge of the board and far from other critical components, so they can receive the coolest air and exhibit less effect on others. Moreover, in order to improve vertical heat transfer, more plated through-hole thermal vias are added between conductive layers. By increasing number of the vias the thermal resistance reduces. Fig. 8 and Fig. 9 show the temperature and temperature gradient of the RF PCB, respectively. Although the improved RF PCB is smaller, the local temperature and temperature gradient are improved about 10 °C comparing with the first PCB.

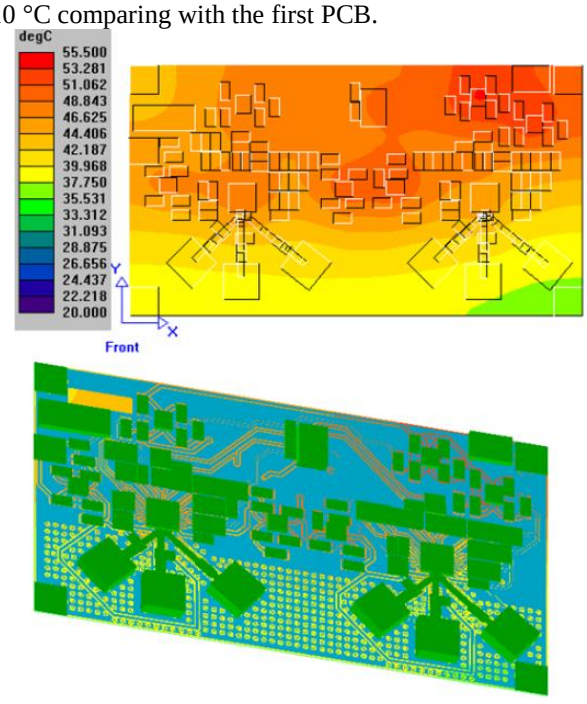

Fig. 8. Temperature analysis of the improved RF PCB

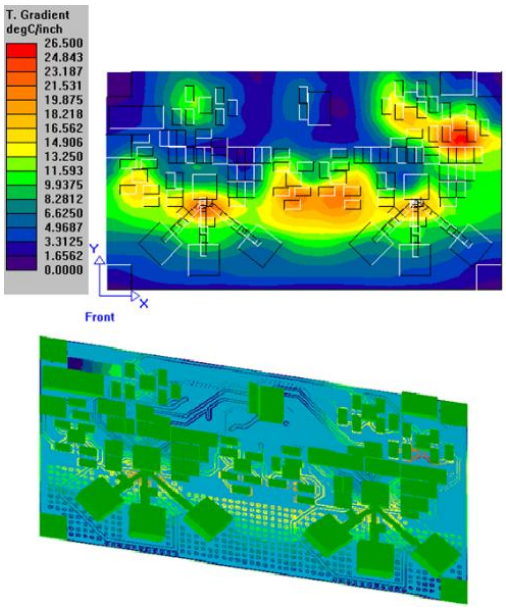

Fig. 9. Temperature gradient analysis of the improved RF PCB

3.3 Frequency Precision Measurement

In order to confirm the validity and performance of the frequency tuning procedure, the Yas and conventional frequency tuning algorithms are implemented in MATLAB. The frequency errors of two algorithms are calculated for desired output frequency ranged from 1GHz to 6800GHz, in 580Hz steps. In order to compare performance and precision of the two algorithms, the mean, maximum, and variance of the frequency errors are calculated. The analytical results of the Yas and conventional frequency tuning algorithms are summarized in Table 3.

Table 3. Analytical results of Yas and Conventional frequency tuning algorithms

	Maximum error	Mean error	Variance error
Yas algorithm	2.8422×10^{-4}Hz	9.4748×10^{-5}Hz	1.009×10^{-4}Hz
Conventional algorithm	2.3286 Hz	0.1590 Hz	0.2505 Hz

It can be derived from TABLE III, that the mean, variance, and the maximum frequency errors of the Yas frequency tuning algorithm are 8201/1, 2482.65, and 2275.4 times better than the conventional algorithm. Moreover, the proposed frequency tuning algorithm has maximum error at the 1.8285GHz output frequency, but the frequency error of the conventional algorithm is maximized at 1.3052GHz, 2.4380GHz, 3.5709GHz, 4.7030GHz, and 5.8365GHz.

3.4 Lock Time Measurement

The designed frequency synthesizer has been simulated in time domain using the ADIsim PLL4 for frequency jump from 1GHz to 3GHz.The simulation result of the output voltage of the lock detect circuit is shown in Fig. 10. The flat region near 2.869ms denotes the locked frequency point.

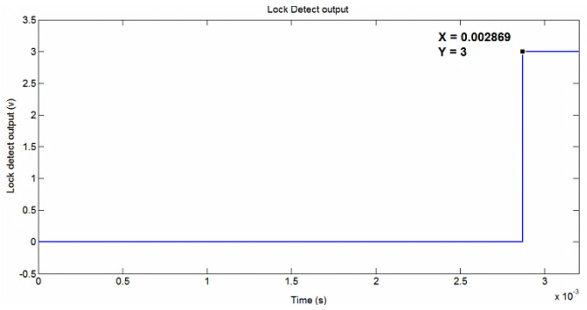

Fig. 10. Simulated lock detect output

4. Implementation and Experimental Result

The RF section and controller and power supply section are implemented on Rogers 4003 and FR4 PCBs, respectively. **Error! Reference source not found.** and **Error! Reference source not found.** illustrate implemented RF section and controller and power supply sections of the proposed frequency synthesizer, respectively.

In order to analyze proper operation of the implemented frequency synthesizer, experimental measurements are performed after temperature stability. These measurements are done using Agilent- CXAN9000A spectrum analyzer and EiP source locking microwave counter. Then the results are exported to MATLAB.

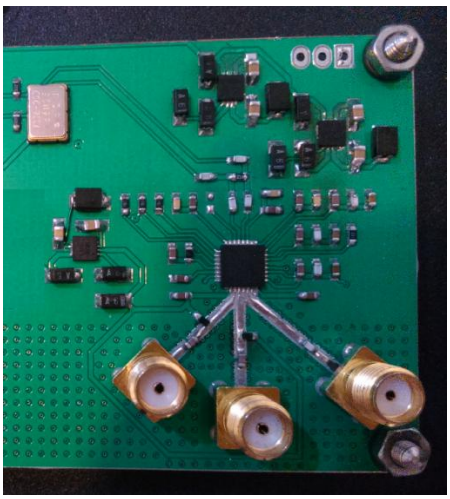

Fig. 11. Implemented RF section of the wide band frequency synthesizer (top side)

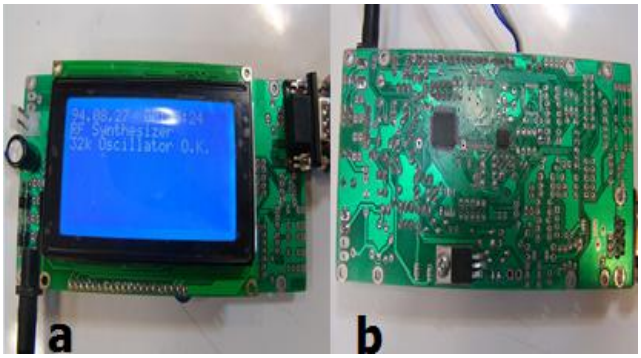

Fig. 12. Implemented controller and supply sections of the wide band frequency synthesizer (a) top side, (b) bottom side

4.1 Phase Noise Measurement

In order to measure the phase noise directly with a swept RF spectrum analyzer, the ratio of the noise power in a 1 Hz bandwidth, at the desired offset frequency to the carrier signal power must be calculated. Measuring the signal spectrum with 1 Hz resolution bandwidth filter is a time consuming task. The bandwidth of the resolution filter can increased, but correction for the noise bandwidth of the filters and analyzer's circuitry must be considered. First, the bandwidth of the resolution filter must be normalized to 1 Hz by (3).

$$\text{Normalized BW} = 10 \times \log(\text{filter BW}/1\ \text{Hz} \times \text{CF}) \quad (3)$$

In (3), CF represents the correction factor of the spectrum analyzer.

The output spectrum of the implemented frequency synthesizer is measured using Agilent- CXAN9000A spectrum analyzer at 3GHz center frequency, 100KHz span, and 100Hz resolution bandwidth. Fig. 13 illustrates measured output spectrum of the implemented frequency synthesizer at 3GHz, 100KHz span, 100Hz resolution bandwidth, and +5dBm output power.

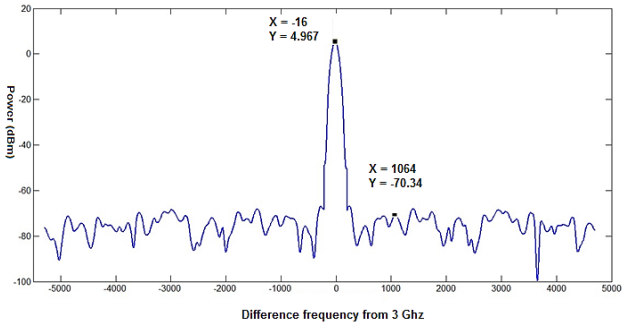

Fig. 13. Measured output spectrum of the implemented frequency synthesizer at 3GHz, 100 KHz span, 100 Hz resolution band width, and +5dBm output power

The normalized resolution band width and phase noise are calculated in (4) and (5). The measured phase noise at 1 KHz offset of the 3GHz is -95.55dBc/Hz.

$$\text{Normalized BW} = 10 \times \log(100 \times 1.0575) = 20.243\ \text{dB} \quad (4)$$

$$\text{Phase Noise @ 1 Khz} = P_n(\text{dBm/Hz}) - P_s(\text{dBm}) - P_{nBW} = -70.34 - 4.967 - 20.243 = -95.55\ \text{dBm} \quad (5)$$

4.2 Frequency Precision Measurement

The theoretical precision measurement can't be reached, because of the noises, temperature instability, and limited performance of the measuring device. Different methods can be obtained to improve accuracy of frequency measurement.

In order to improve frequency measurement, the reference frequency of the frequency synthesizer is synchronized with a standard external frequency of the source locking microwave frequency counter. Because of the limited reference frequency of the implemented frequency synthesizer, the 10 MHz external frequency signal is up converted to 60 MHz by using PLL. Moreover, the heat transfers of the critical points are reduced by thermal insulation.

Yas and conventional frequency tuning algorithms are implemented. The output frequency of the implemented frequency synthesizer is measured experimentally at frequencies which have maximum frequency error. 500 data for each desired frequency were collected. Then, the mean, maximum, and variance of the output frequency are calculated. The maximum measured output frequencies, maximum measured frequency error, mean measured output frequencies, and mean measured frequency error of the conventional and proposed frequency tuning algorithms are summarized in Table 4, Table 5, and Table 6 respectively.

Table 4. Maximum measured frequency of Conventional and Yas frequency tuning algorithms

Desired frequency	Max measured frequency of Yas algorithm	Max measured frequency of conventional algorithm
1.8385GHz	1838499898Hz	1838499824Hz
1.3052GHz	1305199886Hz	1305199754Hz
2.4380GHz	2437999897Hz	2437999742Hz
3.5709GHz	3570899873Hz	3570899652Hz
4.7030GHz	4702999747Hz	4702999548Hz
5.8365GHz	5836499671Hz	5836499474Hz

Table 5. Maximum Measured frequency error of Conventional and Yas frequency tuning algorithms

Desired frequency	Max error of Yas alg.	Max error of Yas alg. (p.p.b)	Max error conv. alg.	Max error of conv. alg. (p.p.b)
1.8385GHz	102Hz	55.48	176Hz	95.73
1.3052GHz	114Hz	87.343	246Hz	188.48
2.4380GHz	103Hz	42.25	258Hz	105.82
3.5709GHz	127Hz	35.56	348Hz	97.45
4.7030GHz	253Hz	53.8	452Hz	96.1
5.8365GHz	329Hz	56.37	526Hz	90.12

Table 6. MEAN Measured frequency of Conventional and yas frequency tuning algorithms

Desired frequency	Mean measured frequency of Yas algorithm	Mean measured frequency of conventional algorithm
1.8385GHz	1838499921Hz	1838499849Hz
1.3052GHz	1305199938Hz	1305199887Hz
2.4380GHz	2437999903Hz	2437999798Hz
3.5709GHz	3570899832Hz	3570899687Hz
4.7030GHz	4702999785Hz	4702999881Hz
5.8365GHz	5836499741Hz	5836499516Hz

Table 7. MEAN Measured frequency ERROR of Conventional and yas frequency tuning algorithms

Desired frequency	Mean error of Yas alg.	Mean error of Yas alg. (p.p.b)	Mean error conv. alg.	Mean error of conv. alg. (p.p.b)
1.8385GHz	79Hz	42.97	151Hz	82.132
1.3052GHz	62Hz	47.5	113Hz	86.58
2.4380GHz	97Hz	39.79	202Hz	82.85
3.5709GHz	168Hz	47.05	313Hz	87.65
4.7030GHz	215Hz	45.7	408Hz	86.7
5.8365GHz	259Hz	44.37	484Hz	82.93

It can be seen that the mean and maximum frequency errors of Yas frequency tuning algorithm are better than the conventional one. Therefore, the proposed algorithm improves frequency tuning precision.

4.3 Lock Time Measurement

In order to measure lock time of the implemented frequency synthesizer, an external interrupt and a timer are used. The lock detection output is the external interrupt connected to the microcontroller's pin and the timer measures the lock time. When the frequency tuning command has sent, the timer resets. The counter stops counting, when the interrupt has occurred. Therefore the lock time is determined by the timer value and counting the frequency. The measured lock time for the frequency jump from 1GHz to 3GHz is 3ms.

5. Conclusion

In this paper, a system-level design and implementation of a portable frequency synthesizer featuring an ultra-wide band (54Mhz to 6800 MHz), high resolution ($\pm$20 ppm over -40/85ºC), fast locking (9ns), low phase noise (-95.55 dBc/Hz at 1kHz offset), tunable output power (-4dBm to +5dBm), and low power(300mA), has been presented.

The new frequency tuning algorithm, called Yas algorithm, has been proposed. By means of Yas algorithm, the frequency precision of the frequency synthesizer was improved. The algorithm has been implemented and tested by MATLAB simulations and experimental measurements. We showed that Yas frequency tuning algorithm has better

precision compared to the conventional algorithm. The proposed algorithm seems to be very useful in high precision measurement systems.

The experimental measurements have been presented to illustrate the proper operation of the system. The experimental results are summarized in Table 8. The implemented frequency synthesizer can be used in applications, such as oscillator of spectrum analyzer, automatic test equipment, FMCW radars, high-performance clock source for high speed data converter, satellite communications, and measurement systems.

Table 9 summarizes the comparison of the implemented system with recently reported frequency synthesizers. Among the mentioned published frequency synthesizers, this work has the wider output frequency range, lower phase noise, and lower power consumption. Instead, it has higher lock time, because of the inherent trade-off between precision and lock time.

Table 8. Experimental Results

Specifications	Experimental Results
Frequency Range	54MHz – 6.8GHz
Tunable output power	-4dBm – +5dBm
Phase Noise	-95.55 dBc/Hz at 1kHz offset
Lock Time	3 ms
Communication ports	RS232, RS485, USB
Internal flash memory	1 GB
Current consumption	300 mA

Table 9. Comparison of recently published frequency synthesizers with this work

Specification	[14]	[15]	[16]	This Work
Output Freq (MHz)	1500-6000	1900-3800	137.5-4400	54-6800
Phase Noise(dBc/Hz)	-111 @100kHz offset	-89.2 @100Khz offset	-111 @ 100kHz offset	-120 @ 100kHz offset
Lock Time	-	22us	-	3 ms
Output power (dBm)	-13.8to -11	-	-	-4 to +5(tunable)
Power Consumption	-	-	2 w	1.5 w

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Analysis of Main Expert-Finding Algorithms in Social Network in Order to Rank the Top Algorithms

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Received: 23/Aug/2016 Revised: 08/May/2017 Accepted: 06/Aug/2017

Abstract

The ubiquity of the Internet and social networks have turned question and answer communities into an environment suitable for users to ask their questions about anything or to share their knowledge by providing answers to other users' questions. These communities designed for knowledge-sharing aim to improve user knowledge, making it imperative to have a mechanism that can evaluate users' knowledge level or in other words "to find experts". Experts are people who are highly talented in a specific field like technology, languages, cooking and etc, and we focused on specific fields in programming languages. There is a need for expert-finding algorithms in social networks or any other knowledge sharing environment like question and answer communities. So companies that looking for hiring programmers can easily find people suit their needs. There are various content analysis and link analysis methods for expert-finding in social networks. Experts can be identified by their behaviors in forums and their relationships in proportion to the questions and answers they share. Therefore, analyzing social networks can provide us with appropriate information. This paper aims to challenge four algorithms by applying them to our dataset and analyze the results in order to compare the algorithms. The algorithms suitable for expert finding has been found and ranked. Based on the results and tests, it is concluded that the Z-score algorithm has a better performance than others. The outcome of this article for enthusiasts is top algorithms for expert finding in question-answer communities. In this paper, first, we will start by introducing the problem of expert finding problem the related works will be presented then algorithms and dataset are introduced and finally results are illustrated.

Keywords: Expert-Finding; Social Network Analysis; Question and Answer Community; Stack Overflow.

1. Introduction

People face various obstacles during their lifetime; from various everyday problems to unique problems and from non-specialized to specialized problems. Everyone tries to solve these problems and will naturally look for those who are experts in that field so that they can solve the problem as soon as possible. Nowadays the first thing that most people do is to turn on their computer and search for an answer on the internet or ask their friends on social networks. But some who are more determined for finding accurate answers to their questions try various online communities where they are able to open a new discussion and ask their questions there. Question and answer (Q&A) communities are particularly suitable for people to share their questions with others and look for consultation from others. But oftentimes there are various, sometimes even contradictory, answers to a question provided by other users. So finding a correct answer would be very challenging. One of the solutions to the problem is to find the experts on these communities and only trust their words. In recent years there has been a great deal of interest in finding a solution for this need. Expert finding is process of identifying users who have the highest level of expertise in specific field of knowledge.

Q&A communities can fit two categories: the specialized and non-specialized. Specialized question and answer communities are those that focus on a particular field. For instance specialized Java communities are designed for questions and answers regarding Java programming. Yahoo Answer is an example of non-specialized question and answer communities, which cover a large number of topics. The objective of this paper is to challenge four algorithms and compare their performance in finding number of experts in specific field. Each algorithm focuses on specific aspects to find experts and that makes them unique to find experts in each field in this paper. But one thing in common in these algorithms is the fact that they try to find most important node in the network their unique way which make them suitable for finding experts in social media networks and These algorithms are the most extendable and Improvable algorithms available in expert-finding. The novelty of this research is to compare 6 main algorithms (including extended ones like directed-Indegree and Z-number and Z-degree) on a large-scale dataset including more than 1 million Q&A data which was hard to pre-process. This large amount of data to be processed makes the results real and trustable for future work of enthusiasts.

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This paper will be presented as described below:

In section 2 we will review the related literature. An introduction for the dataset will be in section 3. Section 4 describes expert finding algorithms while the analysis of the algorithms will be presented in section 5. Section 6 consists of the evaluation process of the algorithms and the conclusions will be presented in section 7. Future work will be presented in section 8.

2. Related Work

The rapid expansion of technology in recent years has resulted in a vast amount of information being published on the internet that can be useful in a variety of ways. One such use is investigated in [1] where they tried to find experts to facilitate knowledge-sharing. In this work they first discuss various expert-finding methods. There are two types of expert-finding, finding experts through analyzing user interaction, e.g. HITS-based algorithms and PageRank algorithm, and content analysis based methods. The authors of this paper state that the link analysis method is more successful than content-based method, but they did express some objections regarding this approach. They concluded that the algorithms like HITS always try to increase user scores. Of course this is only a problem when the dataset does not inherently include negative scoring. Therefore, users' links in their communicational network can be either negative or positive, an example of such links between two users can be seen in figure. 1. op is opinion of user n_j and r is relation of user n_i with user n_j where n_i gives alink point to specific opinion of n_j.

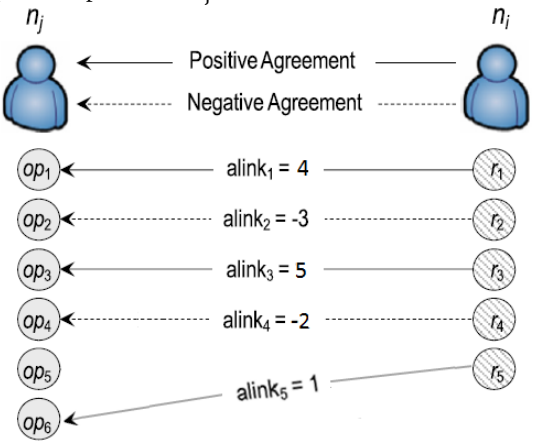

Fig. 1. example of relation of 2 users

They then calculated the users' knowledge level using three types of scores, the number of positive and negative scores, average of positive and negative scores and sum of positive and negative scores.

An explicit semantic analysis was used in study [2]. This work uses the selected dataset (Sina Microlab) as system input and converts it to a vector using TF-IDF[1] algorithm. Afterwards they used a proximity cosine to estimate similarity between users and then used an explicit semantic analysis to find experts from a particular definition in Bayesian networks. The general idea is to estimate an individual's x_i expertise in topic Q which results in $P(x_i|Q)$. To find this estimation, conventional methods, like lingual models, use various Bayesian network definitions but this work assumed that the value of $P(x_i|Q)$ is equal to that individual's expertise similarities in topic Q. Then they obtained "Follow" interactions which in turn allowed them to calculate user interaction, degree of collaboration and users' influence on each other's expertise. In the end, they used each user's similarity value and the score obtained in user interaction analysis to calculate the individual's final expertise.

Information overload is one of the aspects of Expert finding. Many techniques for reducing information overload is surveyed which can lead to finding interested group of people and thus finding experts out of them by implementing social network analysis methods on those groups and mine the experts [3]. In [4], users' reputation is considered as a factor for finding experts in Q&A forums. Two techniques are presented in [4], the first technique is based on asker and answerer's reputation in various threaded discussions and the second technique is based on user's answer quality which is based on category which the user participates in. In the first technique, co-existing users in discussion is extracted and modeled and in second technique semantic similarity among posts of co-existing users for a given topic is a basis for quality of answers. Three parameters are given for finding experts in a specific topic or answer in Yahoo Answer. These parameters are: user's knowledge profile, user reputation and link analysis [5].

This study, uses data mining to obtain the data related to each user's Q&A History and uses them to create a knowledge profile for each user. This profile, shows the topics of each user's knowledge. This information along with supplementary information, e.g. topic and date, are extracted from the dataset and then converted into vector space, in other words each user has a vector that corresponds to his/her knowledge. After creating user knowledge profile, each user is awarded a knowledge score, which depends on where that particular topic is usually mentioned (title, question description or answer) and how similar that particular topic is to the user's knowledge.

User Q&A record is used in various context for user reputation score derivations. This information includes the number of answers and the number of times that the answers were chosen as the best answer, as well. In link analysis, the users' network based on the links between users in the Q&A community is formed and then uses an algorithm to analyze user interaction. There are various algorithms that can be used for such purposes including the PageRank algorithm, HITS or one can use social network Metrics such as degree, closeness and betweenness centrality. Finally user expertise is calculated by summing these three scores.

[1] Term Frequency–Inverse Document Frequency

Work [6] showed that topic-based expert-finding can be achieved through Latent Topic Modeling. For example user expertise in a particular topic can be modeled based on the answers and comments that they provide on that particular topic. This method extracts user interests from user profiles and then finds the experts by using the questions and answers, obtaining the user score in each topic and using link analysis. The size of the dataset is particularly important in this method, since one cannot employ unsupervised or weakly supervised methods for user interest extraction when dealing with large datasets.

Study [7] proposed the CRAR[1] method, which obtains user authority using link analysis and does so based on the class or classes associated with that particular question and relevant topics (obtained from content analysis). In other words, first, user similarity is determined based on users' knowledge sharing logs, this user similarity is the basis of network creation. Next, link analysis is used on the network to rank expert users. This algorithm employs both content and ink analysis to find the experts.

Unlike previous studies, [8] uses methods other than the typical content and link-based analysis. Here they first introduce the conventional methods of expert-finding and then propose solving this problem by predicting the empty values in the adjacency matrix. The process of filling the matrix is employed in various fields, e.g. computer vision [9] and collaborative filtering using a weighted trace-norm regularizer [10]. In most cases the process is viewed from the perspective of filling matrix's empty values. The empty values can be filled in by using the adjacency matrix itself but this study used matrix rank function to show that this is an NP-hard problem (the rank of a matrix is the sum of its non-zero rows). Therefore, this problem becomes a nuclear norm optimization problem. They then used this norm to obtain the matrix values and user expertise.

Another problem in expert-finding is to find the exact number of people that have high expertise levels. For example assume that we are going to recommend K people as experts, then how, and on what basis, should we determine this K value. Moreover, the expert-finding problem can be considered by determining scores for each answer [11]. In [11], an automated method was designed by using the text and topic information within each answer. This information can be used to provide a classified model of answers and to determine the scores of answers at each level. The text information includes personal information, forum-relating information, the variety of characters and specific words in the text, and the statistical information pertaining to each answer.

The problem of methods which relies on users' Q&A history, is the sparsity of Q&A forum data. The problem of expert finding can be seen from the view point of learning ranking metric embedding. To find experts from this point of view, a novel ranking metric network learning framework was designed and then a random walk based learning method with recurrent neural network was developed to rank metric network embedding [12].

In [13], the focus was on evaluating a method which used *Learning to rank* (LTR) to rank feature vectors based on their relevance. This evaluation more concentrates on the quality of ranking function. The DRM method has been proposed in another resource [14]. DRM is a content analysis method which refers to the way that questions are suggested to the users and can be used to find the suitable users for answering any specific question. DRM is a probabilistic topic-sensitive method which uses the PLSA model to analyze each question's subject and then models each user in the roles of the asker and answerer based on his/her questions and answers. Implementation of this method is divided into two parts, the independent part and the dependent part. In the independent method (IDRM), user's cooperation in the topic are the only things that are taken into account but the dependent method (DDRM) also includes the relation and interactions between the users.

Using User interest to find experts is the focus of [15], which determines user interest from users' answer logs. They proposed two methods for expert-finding word-based and topic-based. The first method uses a lingual model and TF-IDF to model the users which assigns each question to one and only one topic category while the second method (also called STM[2]) can assign each question to multiple categories, which leads to more realistic models and better results.

In this paper we attempt to compare four expert-finding algorithms by applying them to an identical dataset. To this end we will introduce the dataset in the next section and then we will describe the conventional algorithms.

3. Dataset

We require a dataset relevant to Q&A communities, therefore we used the Stack Overflow dataset, which is a Q&A community in the Stack Exchange network. Stack Exchange is a network of 159 Q&A communities, each community in this network is created by experts and enthusiasts in a particular topic. Each of these communities consists of high quality questions and answers related to a particular topic and experts can be found in these communities based on user activities.

In the current paper the basis of knowledge in expert-finding is the ability to answer questions, Therefore the answers must be only about that particular question and should not include other discussions and personal opinions about that question. Stack overflow's questions and answers possess this key feature. We need to extract this kind of answers since unrelated discussions may take place in non-answer replies which, obviously, cannot be a reliable basis for evaluation of the users' knowledge.

This website revolves around the questions, when a user asks a question, the website creates a discussion around that question and sets the discussion to "open",

[1] Category Relevancy based Authority Ranking

[2] Segmented Topic Model

and other users can then answer that question. The question remains open until such time that the asker chooses one as the "best answer" (or until the best answer is chosen via the voting system), the discussion will be "closed" the moment that one of the conditions is satisfied and no one can post an answer afterwards.

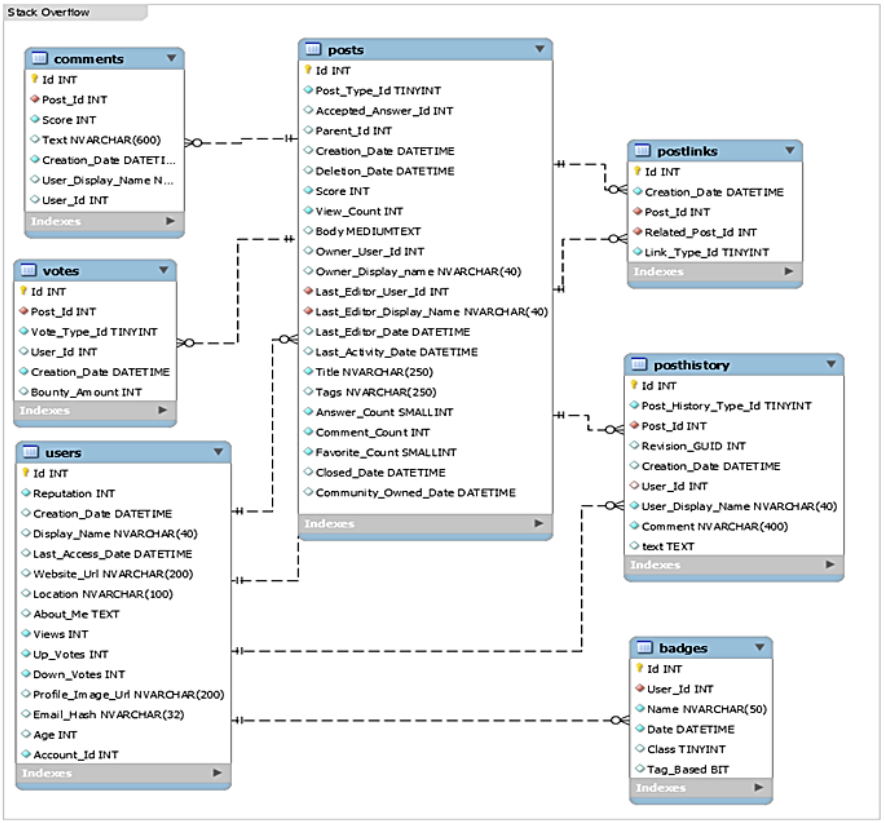

Fig. 2. Stack Overflow database scheme

We used the website's data extraction user interface in order to extract the required data. The information regarding the users, questions and answers, etc. were used to create database tables. Brief database scheme including important tables is illustrated in figure. 2.

As previously explained, to determine an individual's expertise, we need a clear and specific topic. In order to find the topics we used the "Tag" feature and found that C# and JavaScript were among the most discussed topics in Stack Overflow, which is confirmed by the community as well. The top 20 tags that generated the highest traffic are presented in figure. 3.

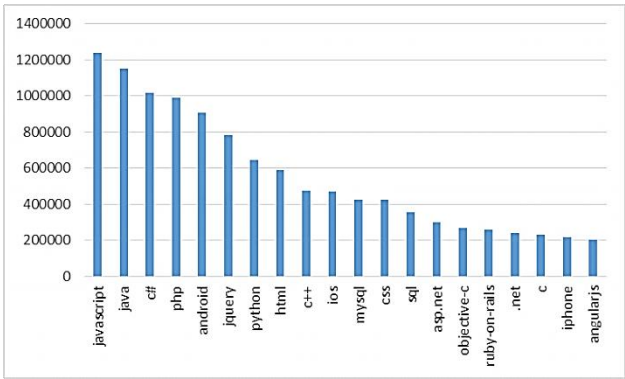

Fig. 3. Question count related to each tag in stack overflow

Therefore, we extracted the data related to the questions and answers about C# and JavaScript topics separately from 1st January 2014 to 1st January 2015. Following extraction and some preprocessing (including removing users that didn't have an ID and repetitive results due to similar tags), in the C# topic, we were left with 234877 answers from 89519 users while there were 354509 answers from 159408 users in JavaScript. After analyzing the dataset and extracting the desired data, we created table. 1 from the 2014 data regarding both JavaScript (JS) and C# tags.

Table 1. Data about extracted data

	No. of users	No. of questions	No. of answers	No. of questions without answer	Rate of answer
JS	159408	239316	354509	7.8%	86% By 25% of Users
C#	89519	167455	234877	9.1%	84% By 25% of Users

We also extracted score of each answer and used them in order to calculate score of each user in 2014 in each tag. These Scores will be used to evaluate algorithms' performance. Table. 2 shows a row of extracted data that illustrates an answer information in stack overflow.

Table 2. sample of extracted data

Questioner ID	Answerer ID	Question ID	Answer ID	Accepted Answer ID	Question Creation Date	Answer Creation Date	Answer Count	Question Score	Answer Score
2711395	474569	24362425	24362729	24363725	6/23/2014 9:21	6/23/2014 9:38	4	10	12
2711395	248703	24362425	24362812	24363725	6/23/2014 9:21	6/23/2014 9:42	4	10	3
2711395	343266	24362425	24363725	24363725	6/23/2014 9:21	6/23/2014 10:32	4	10	20
2711395	921321	24362425	24366141	24363725	6/23/2014 9:21	6/23/2014 12:37	4	10	2

4. Expert Finding Algorithms

As previously discussed there are various algorithms for expert-finding in social networks and the most notable ones are the PageRank, HITS, In-degree and Z-score algorithms. Next we will explain these algorithms and investigate their scoring methods.

4.1 Pagerank

This algorithm was first proposed in [16]. The goal of this algorithm was to determine the importance of various websites based on their referrals, but later it was used in various another context, including expert-finding, as well.

The PageRank algorithm is based on a user's random browsing between internet pages. The algorithm's idea is that a user starts in a website and randomly clicks on one of the links on that website and continues doing so during his/her internet session. Then the algorithm assigns importance to each page based on the number of views, but there is always the possibility that the user gets trapped in a loop of pages. To solve this problem, a jump possibility is added to the algorithm so that the user can jump out of the loop, this jump possibility is not limited to loop trap situations though and it has a fixed rate of happening at any given time though the jump possibility increases to 100% when the user is trapped in a loop. In other words the jump feature works like this:

- When the node is not connected to any other nodes, then there will be a jump.
- If there are other nodes connected to the present node, then there is a possibility 1-d (0<d<1) that the searcher jumps and consequently the possibility that it continues to the connected node is d. Here d is a damping factor and it is usually assumed to be equal to number between 0.85 to 0.9 in scientific studies.

Each we assume each node in the social network is a user, then each user's PageRank is calculated using Eq. (1), where PR(u) is Pagerank score of user u, d is the damping factor and represents the possibility of moving to the next connected node and therefore 1-d is the jump possibility, B_u is the set of nodes that are connected to node u, L(v) is the number of out-going edges of node v and N is total number of users.

$$PR(u) = \frac{1-d}{N} + d\left(\sum_{v \in B_u} \frac{PR(v)}{L(v)}\right) \quad (1)$$

4.2 HITS

This link analysis based algorithm has two parameters, hub and authority, that need to be updated every time that a node (user) or link (answer) is added. This algorithm also uses user interaction matrix and updates the matrix, hub and authority after an infinite repeat of the algorithm. To prevent diverging matrix values we need to normalize the values, and the algorithm provides this mechanism as well.

The HITS algorithm for expert-finding in Q&A communities assigns a hub and an authority parameter to each node and increases that node's "hub score" every time it asks a question while the "authority score" increase every time the node provides and answer. A node's authority is calculated by summing the hubs of every node that points to p (Eq. (2)) and hub of user p is equal to sum of the authority of users (i) that p points to them (Eq. (3)).

$$auth(p) = \sum_{i=1}^{n} hub(i) \quad (2)$$

$$hub(p) = \sum_{i=1}^{n} auth(i) \quad (3)$$

At first, when the user interaction network is formed, hub and authority values of every node is set to one and then Eq. (2) and (3) are used in order to update these parameters. A user's answers are essential to determining his/her expertise therefore authority will be used for final user ranking.

4.3 In-Degree

Degree is one of the centrality metrics in social networks and is equal to the edges entering the node. First we have to obtain the adjacency matrix of the Q&A network and the sum of the indices in a column is equal to the degree index, expect that here we set number of answers given by destination node (user) to starting node as edge weights. When using weighted edges, the degree metric is called "weighted In-degree" instead.

4.4 Z-Score

As it is obvious that answering multiple questions is a sign of expertise in a topic, asking questions is a sign that the user lacks knowledge. Therefore the Z-score method combines the Q&A Pattern of users. Here, assuming that the user has asked *q* questions and has provided a answers, a user's Z-Score is calculated by Eq. (4).

$$Z = \frac{a-q}{\sqrt{a+q}} \quad (4)$$

Obviously the Z-score would be zero if the number of questions and answers are equal, it would be positive if *a* is greater than q and would be negative in other cases. This value is called the "Z number" when one uses the number of questions and answers while it is called the "Z

degree" when one uses the In-Degree of the node as *a* and Out-Degree as *b*.

4.5 Algorithm Analysis

The PageRank algorithm is very sensitive to the knowledge environment. For example if individual B answers to individual A's question and individual C answers a question posed by B, then C has to score higher in expertise since he/she could answer the relative expert from the former interaction. But the question posed by A may have been in the C# field while the question posed by B may have been in JavaScript, which negates the previous conclusion. Therefore the analysis must be confined to a single topic which is exactly what we have done in this paper for two different datasets.

As it is mentioned in [11], there are situations where the HITS algorithm gives erroneous results as well. Take figure. 4 as an example, nodes 1, 5 and 10 should receive the highest scores but HITS algorithm gives high authority scores to 1, 6, 10, 11 and 12 and gives a score close to zero to node 5. This occurs since node 13 is connected to node 10 (high authority node) therefore, node 13 has a high hub score, which in turn increases the authority scores of nodes 6, 11 and 12. on the other hand, nodes which are connected to node 5 have low hub scores (relative to nodes connected to 1 and 10), therefore node 5 gets a low authority score.

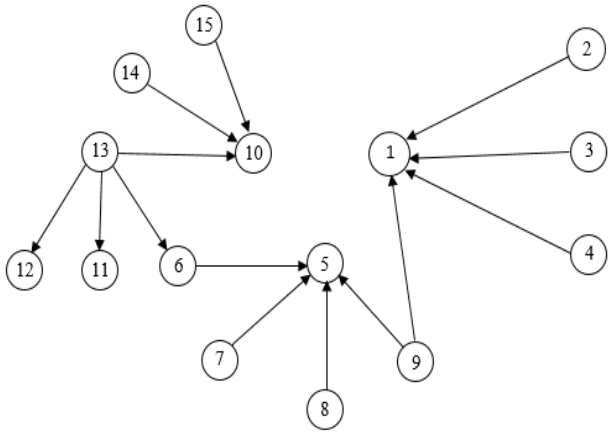

Fig. 4. Example of HITS algorithm

Then we should apply the algorithms to the information extracted from the dataset (i.e. the questions and answers) and obtain each user scores based on each algorithm. The explanation for the implications of each algorithm is as follows.

The PageRank algorithm inherently assigns higher importance to nodes that have higher number of reference (the PageRank algorithm does not take into account the quality of a reference because the definition of a reference quality refers to context of the reference which is not SNA approach) and in the context of Q&A communities, this means that the user has been active in answering the questions which are the basis of user expertise. Authority in HITS depends on the number of connections to other nodes and, here, it is a representation of the answers given by the node and even questions which this node has answered. As explained previously In-

The Z-score algorithm assigns user expertise score by using the concept of questioning and answering rate prediction and calculating users' standard deviation from that prediction. This is a purely mathematical method and its analysis is not based on social networks' structures and concepts, which is not favorable, but we can get good results by combining the Z-score algorithm with Degree Centrality metric.

In-degree is the simple metric in social network analysis, yet it also gives us a good understanding of the social network. In this context In-degree represents the number of unique users that the node (user) has given answer to. To improve this approach, we created weighted edges by adding weights to each edge that connect any two nodes. A weighted In-degree represents the number of answers a user has given to others in that particular dataset and time period.

5. Implementation

First, we have to define the user interaction network. A network consists of nodes and edges and here the nodes represent the users while the edges represent the answers given by the users. Figure. 5 shows a part of the user interaction network and the top 10 users as reported by the In-degree algorithm. Node A has the highest In-degree in the user interaction network, hence it is also the biggest and darkest node in the network. It should be noted that this network is an asker-answerer network and edges are drawn from asker to answerer.

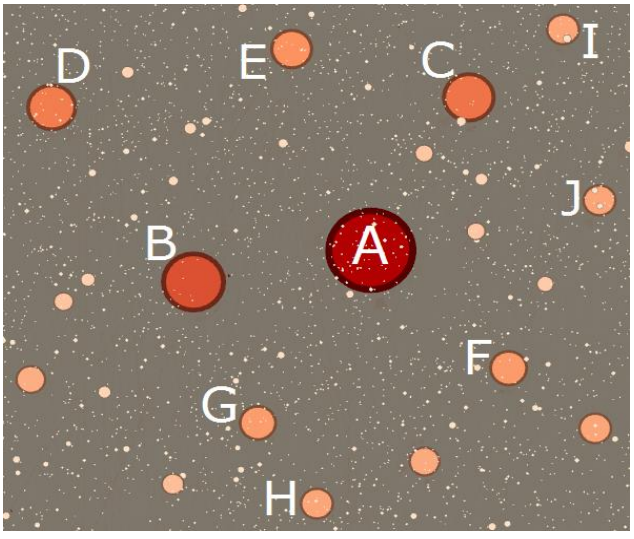

Fig. 5. Part of User Interaction Network

Table 3. Scores obtained by top 10 users in C#

Symbol	UserID	PageRank	In-Degree	Weighted In-Degree	HITS (Authority)	Z Number	Z Degree
A	3010968	0.0025	1845	2102	0.00676	43.5	40.5
B	22656	0.0036	1357	1452	0.00497	37.9	36.6
C	284240	0.0014	1090	1191	0.00399	33.0	31.6
D	1159478	0.0160	1063	1143	0.00390	33.7	32.5
E	993547	0.0019	894	939	0.00328	30.4	29.7
F	301857	0.0059	807	871	0.00296	29.5	28.4
G	470005	0.0010	794	850	0.00291	29.1	28.1
H	1081897	0.0011	709	743	0.00260	27.2	26.6
I	1197518	0.0009	708	756	0.00259	27.4	26.6
J	23354	0.0018	707	774	0.00259	27.4	26.3

Degree is a measure of the number of entering edges and in this context it represents the number of unique individuals the user has answered. Z-number depends on the number of answers and questions extracted from the dataset. the algorithm assigns negative values to the Z-number when question count passes answer count of each user while providing more answers by the user increases the score. Z-Degree, assigns positive values to In-degree and negative values to Out-degree and determines expertise based on those values.

Table. 3 shows the scores obtained by 10 different users. The marked scores are the highest scores in each algorithm (meaning these scores are obtained by the most expert users as indicated by that particular algorithm). For example, user 1159478 has a score of 0.0160 in PageRank algorithm while the most expert user as predicted by In-degree, weighted In-degree, HITS, Z-Number and Z-degree algorithms was user 3010968 which obtained scores of 1845, 2102, 0.00676, 43.5, 40.5 respectively.

6. Evaluation

We removed users that had less than 50 answers to analyze the more active users to do the evaluation process. In order to evaluate each algorithm, we sorted the top 50 users by score they achieved based on each algorithm in mentioned time period in each Tag. We also sorted the top 50 users, based on scores they achieved according to their answers in the Stack Overflow in mentioned time period in each Tag. Then we compared the algorithm predicted top 50 with the top 50 that was extracted from Stack Overflow and determined how many common users are in each 50. The reason that we chose top 50 users is the fact that in specific tags in stack overflow, score of people suddenly decrease at some points and we can say for sure that top 50 users in each tag answer a large amount of questions.

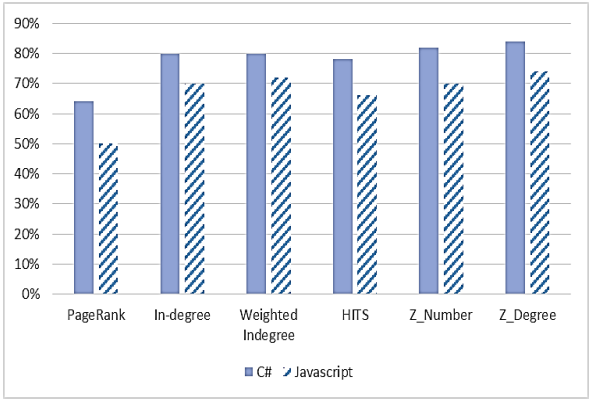

Fig. 6. Performance of each method

Figure. 6 shows the ratios of users that each algorithm successfully predicted, obviously, a higher ratio means that particular algorithm has had a better performance. In other words this figure shows the accuracy (in percentage) of each algorithm in finding experts in C# and JavaScript areas in Stack Overflow in 2014.

As can be seen in figure. 6, Z-degree algorithm had a ratio of 84% which translates to the best performance among all algorithms. All algorithms except the PageRank algorithm gave almost similar results since they solely focus on the answers provided by the user. The score given to each user in the dataset is based on the users' opinions and does not take into account that "a user should get more credit when he/she answers the questions of people who have answered to another expert's questions previously". Stack Overflow dataset scores rank the people based on scores they receive. The scores come from up-votes they take by other users and that up-vote is naturally come from quality of answer, reputation and being best answer by questioner's choice. That is why PageRank has had the worst performance. The reason that the Z-score algorithm had the best performance between the other 3 algorithms is that this algorithm also takes into account the questions posed by the user and treats them as an indication that he/she lacks knowledge.

7. Conclusion

This paper compared various expert-finding algorithms in an online Q&A Forum. One Million Questions and Answers were extracted and pre-processed in order to use in expert-finding algorithms. It was shown that performance of each algorithm depends on scenario and structure of network. Each of these algorithms assigns scores to users in their own unique way and then reports the user with the highest score as the expert. To achieve our goal, first, we discussed the various algorithms and then extracted the desired datasets from the Stack Overflow database and prepared the data for pre-processing. Then algorithms were applied to the users' questions and answers and results were compared with the scores given in the community itself in order to obtain each algorithm's performance. The results showed that the Z-Degree algorithm had the highest percentage of expert-finding therefore it also had the best performance. Overall Z-Number, In-Degree, HITS and Pagerank are in the next ranks, respectively.

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Lifetime Maximization by Dynamic Threshold and Sensor Selection in Multi-Channel Cognitive Sensor Network

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Received: 10/Sep/2017 Revised: 02/Dec/2017 Accepted: 02/Jan/2018

Abstract

The tiny and low-cost sensors cannot simultaneously sense more than one channel since they do not have high-speed Analog-to-Digital-Convertors (ADCs) and high-power batteries. It is a critical problem when they are used for multi-channel sensing in cognitive sensor networks (CSNs). One solution for this problem is that the sensors sense various channels at different sensing periods. Due to the energy limitation in these scenarios, the lifetime maximization will become an important issue. In this paper, maximizing the lifetime of a CSN is investigated by selecting both the cooperative sensors and their detector threshold, such that the desired detection performance constraints are satisfied. This is a NP-complete problem, and obtaining the optimum solution needs exhaustive search with exponential complexity order. Here we have proposed two convex-based optimization algorithms with low order of complexity. First algorithm applies the known instantaneous Signal-to-Noise-Ratio (SNR) and obtains the proper detector thresholds by solving an equation for every channel. Investigation the effect of detector thresholds on the energy consumption, the false alarm probability and the detection probability shows that we can minimize the detector thresholds such that the detection constraints are met. In the second algorithm in order to reduce the needed time for obtaining answers, the Bisection method is proposed for determining detector thresholds. Because knowing the instantaneous SNR is difficult, we have investigated the performance of the second algorithm by average value of SNR. Simulation results show that the proposed algorithms improve the performance of the network in case of lifetime and energy consumption.

Keywords: Cognitive Sensor Network; Detection Probability; False Alarm Probability; Lifetime; Multi-Channel Cooperative Spectrum Sensing.

1. Introduction

With the increasing use of wireless applications, the lack of spectrum issue has emerged. Cognitive radio networks (CRNs) have been proposed to overcome this issue. In these networks secondary users (SUs) sense the spectrum to find and access free sections of the licensed bands as long as they do not cause harmful interference with the primary users (PUs). Because of fading or shadowing effects, SUs might not be able to reliably monitor all PUs. Therefore, cooperative spectrum sensing (CSS) schemes are proposed in which the detection results from spatially distributed multiple sensors are combined to make a final decision [1].

If an SU performs both sensing the channels and transmission on the detected idle channels, it cannot sense and transmit simultaneously, because of hardware limitations, so it reduces the opportunistic access efficiency. Also, one SU may fail to sense all the channels simultaneously. Therefore, CSN composed of tiny and low-cost frequency sensors is one solution, where sensors are used for spectrum sensing [2] [3], and then the sensing results are sent to the SUs. The CSN provides higher throughput for the SUs, and better protection of PUs against interference.

Multi-channel spectrum sensing is ambitiously proposed to efficiently monitor a wideband spectrum which is used by multiple PUs. This functionality causes to increase the SUs throughput, to improve spectrum's maintenance, and to reduce transmission interruptions, while it increases the complexity and requirements for adequate quality of sensing. The limited sampling rate of ADCs complicates the multi-channel spectrum sensing [4]. A practical method is monitoring the channels separately, which in this method, sensors cooperate with each other to sense all the channels.

Simple implementation, low computational complexity and energy consumption are the reasons that determine energy detector (ED) as a useful detector for multi-channel sensing [4]. The cooperation between cognitive sensors improves the performance of this technique, too. Employing an array of EDs, each of which detects one frequency channel, has been used for multi-channel joint detection.

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This method enables SUs to simultaneously detect PU signals across multiple channels [5], but this scheme is complicated costly and non-applicable for such a CSN.

On the other hand, ED with fixed threshold is sensitive to noise and it cannot perform well in low SNR. So, it leads to interference with PUs, and decreases the throughput of SUs. Dynamic threshold selection for energy detector improves its performance [6], because the threshold is adjusted on demand with regard to the different SNR. Also, dynamic threshold selection is a way to energy conservation of a cognitive network [7].

Because of small size and weight of sensors, there are limitations on their energy and cost. These physical constraints of sensors and the prohibitive costs to replace the depleted sensors in the CSNs make energy an important consideration to design a long lifetime network [3]. Mechanism of energy consumption of a CSN has a great impact on the network lifetime. Lifetime extending techniques can improve the energy utilization and hardware efficiencies. Therefore, reducing the energy consumption and balancing the residual energy of sensors are both critical in CSN design. If all the sensors perform sensing, it leads to high energy consumption and it raises the false alarm probability without increasing significant detection probability [8]. So sensor selection is a way to reduce energy cost while satisfying sensing quality constraints. In this paper, two ways are investigated for reducing the energy consumption and balancing the residual energy of sensors in a CSN. First is sensor selection for CSS, and the second is dynamic threshold selection for ED of the sensors. The two problems are combined and simultaneously solved.

1.1 Prior Works

[7] is a rich survey on the energy efficient schemes for CSS. Optimization of sensing nodes number and sensing settings are two main directions of possible energy conservation methods in CSS [7]. Reducing number of sensing nodes have been investigated with methods such as censoring [9], determining the optimum number of SUs [10]- [11], clustering [12], and node selection [13], in order to reduce energy consumption of CSS. They assumed monitoring of only one channel which is utilized by one PU. Also, methods such as energy harvesting (EH) [14], compressive sensing (CS) [15], and clustering [16], have been proposed for energy conservation of multi-channel CSS in a CRN. The former two methods are complicated and needs particular capabilities, but the third method is applicable in any CSN.

The detector threshold selection is a way of CSS settings optimization for energy conservation which has been proposed in studies such as [17]-[18]. In [17], both the sensor selection and ED threshold optimization for CSS in a CSN was investigated, although for monitoring only a single channel. In [18], assuming multi-channel CSS, schemes for assigning nodes to sense various channels, and then threshold optimization were proposed. They used clustering method for assigning all the nodes to adequate channels, to increase the overall throughput. Although this node assignment scheme improves energy conservation, it uses all the sensors for sensing, which is not optimal, meanwhile it causes to increase the false alarms. Also, the fixed thresholds were determined which is not optimum due to the time-varying nature of the lifetime problem. Jointly determining the optimum threshold of detector of sensors, and selecting sensors for all channels is a challenging problem, because the selected sensors change for different channels, and it is efficient to dynamically select threshold of EDs for selected sensors. The lifetime problem becomes more complicated, because the status of channels and the energy of sensors changes by time (i.e. channels are time varying and some nodes run out of battery). This paper pays attention to all of these challenges in node selection and threshold determining for the multi-channel CSS problem. In this paper, both dynamic thresholds and sensor selections for cooperative multi-channel sensing are assumed, with aim to energy conservation and lifetime maximization. For a CSN, two algorithms are proposed to assign the adequate sensors to various licensed channels, while the optimization of the detector threshold is done for reducing energy consumption and increasing the network lifetime. This paper aims to prolong the CSS lifetime while improving the detection performances, too. In the first algorithm the detector thresholds are optimized for cooperative sensors, but it needs a long time for finding the optimal solution. Second, another algorithm is proposed which finds efficient solution at a shorter time.

The rest of the paper is organized as follows. In section 2, system model is expressed. Section 3 discusses the problem formulation based on the instantaneous SNR of sensors. In section 4 the algorithms are presented. The generalization of the algorithm to the average SNR scenario will be presented in section 5. The simulation results are explained in section 6. Finally, the conclusions are presented in section 7.

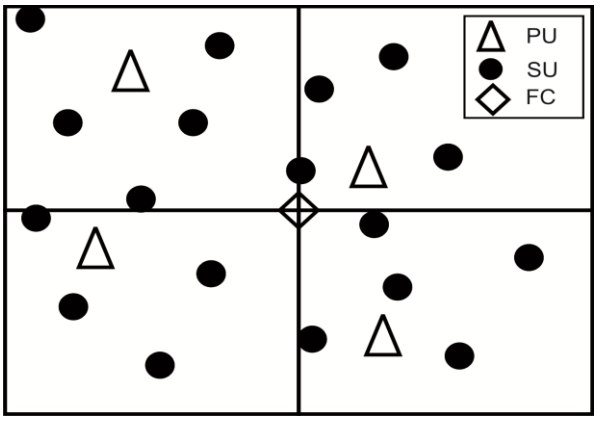

Fig. 1. A sample of system model.

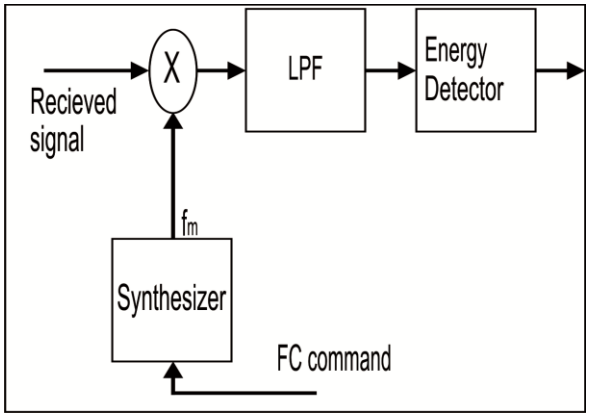

Fig. 2. The receiver circuit of every cognitive sensor.

2. System Model

We consider a CSN with an FC and N sensors which are distributed uniformly. We assume the wideband is divided to M channels with the same bandwidth. M PUs are distributed uniformly and use the channels to transmit their signals with the same modulation, while each PU can use from a single channel. A sample CSN is depicted in **Error! Reference source not found.**. Because sensors have limited hardware, so a tiny sensor cannot sense more than one channel, simultaneously. A solution is proposed in which the CSN can simultaneously sense more than one channel by cooperation between sensors. It is assumed that every sensor is equipped with a receiver circuit which composed of a synthesizer, a narrowband filter, and an ED. The simple and low-cost receiver circuit is plotted in **Error! Reference source not found.**. In fact the narrow-band detector can only scan one PU at a time. However, the synthesizer tunes frequency with a command from FC to the center frequency of a channel. Because of low complexity energy detector is proposed for sensing the spectrum. $\gamma_{m,n}$ denotes sensor *n* detector threshold for the channel *m*. Generally, the optimal thresholds are not equal even in case of sensing a single channel with equal channel gains at all sensors, but an equal threshold for sensing a channel is asymptotically optimal when the number of sensors goes to infinity [15]. For reducing the complexity of the algorithms, it is assumed that all the sensors assigned to a single channel use equal energy detector thresholds (i.e., $\gamma_{m,n} = \gamma_m$), but in different durations of sensing this thresholds are determined dynamically. The signal energy at channel *m* is measured by sensor *n* as: $T_{m,n} = \sum_{k=1}^{K} |x_{m,n}(k)|^2$, where $x_{m,n}(k)$ denotes the k-th sample of the discrete received signal of channel *m* that is observed by the n-th node, and K is the number of samples which is calculated as δf_s, where f_s is the Nyquist sampling rate of detector according to the channel bandwidth, and δ is the sensing time. In table 1, the description of each notation used in the paper is shown.

We define two hypotheses for every sensor. The first, i.e. $H_{0,m}$, says that the m-th PU is not transmitting, i.e. channel *m* is idle, and the second, i.e. $H_{1,m}$, says that the m-th PU is transmitting, i.e. channel *m* is busy. So we have:

$$\begin{cases} H_{1,m};\ x_{n,m}(k) = g_{n,m}.s_m(k) + v_{n,m}(k) \\ H_{0,m};\ \ x_{n,m}(k) = v_{n,m}(k) \end{cases} \quad (1)$$

$$\begin{cases} H_{1,m};\ T_{n,m} \geq \gamma_m\ ;\quad T_{n,m} \sim \mathcal{N}(0, {\sigma_{1,n,m}}^2) \\ H_{0,m};\ T_{n,m} \leq \gamma_m\ ;\quad T_{n,m} \sim \mathcal{N}(0, {\sigma_V}^2) \end{cases} \quad (2)$$

The k-th sample of transmitted primary signal on channel m is denoted by $s_m(k)$, that is assumed to be an i.i.d random process with zero mean and variance σ_S^2. $v_{n,m}$ is the Gaussian i.i.d random noise with zero mean and variance ${\sigma_V}^2$, and it is assumed that s_m and $v_{m,n}$ are independent. $g_{m,n}$ denotes the channel gain between the m-th PU and sensor *n*. The path loss, Rayleigh fading and shadowing effects are considered in order to model the PU-sensor channels. Hence; the channel gains are modeled as [19]:

$$g_{m,n} = 9^{\frac{20\log\left(\frac{\Lambda}{4\pi d_{m,n}}\right)+z_{m,n}}{20}} \widetilde{g_{m,n}} \quad (3)$$

which $\widetilde{g_{m,n}}$ is a standard complex Gaussian random process (Rayleigh fading), $z_{m,n}$ is a Gaussian random variable (in dB) with zero mean and variance σ_z^2 (Lognormal shadowing), and the expression $\left(\frac{\Lambda}{4\pi d_{m,n}}\right)^2$ is free-space path loss component, when Λ is the wavelength and $d_{m,n}$ is the distance between the PU that uses channel *m* and sensor *n*.

Under the hypothesis $H_{1,m}$, the ratio of measured signal of sensor *n* from the m-th PU to the noise power is defined as [13]:

$$SNR_{m,n} = \frac{p_t |g_{m,n}|^2 \sigma_S^2}{\sigma_v^2} \quad (4)$$

We assume the FC knows the instantaneous received SNR of the sensors. Since the goal of this paper is not the SNR estimation, we ignore the estimated SNR error. Although, this assumption seems unrealistic for some scenarios, it does not have effect on the procedures of the proposed algorithms [9]. The sensor selection can be done based on the average SNR or the estimated SNR, similarly, which is discussed in section 5.

There are two important metrics for the spectrum sensing quality which are called as false alarm and detection probabilities. The larger detection probability and the lower false alarm probability of a node provide more reliable spectrum sensing by the node. These metrics for sensor *n* which senses channel *m* are calculated respectively as [13]:

$$P_{f_{m,n}} = P(H_{1,m}|H_{0,m}) = Q\left(\left(\frac{\gamma_m}{\sigma_v^2} - 1\right)\sqrt{\delta f_s}\right) \quad (5)$$

$$P_{d_{m,n}} = P(H_{1,m}|H_{1,m}) = Q\left(\left(\frac{\gamma_m}{\sigma_v^2} - SNR_{m,n} - 1\right) * \sqrt{\frac{\delta f_s}{2SNR_{m,n}+1}}\right) \quad (6)$$

Here $Q(.)$ denotes the complimentary distribution function. It is noted that the false alarm probability does not depends on the received SNR of sensors, but the detection probability depends on the sensors received SNR.

It is assumed that the FC uses the logic OR rule to fuse the decision of sensors [9]. According to the logic OR fusion rule, if at least one sensor detects the primary signal transmitting on channel *m*, the final decision shows that the PU is transmitting. If all sensors participate simultaneously in sensing, it leads to high energy consumption and it raises the false alarm probability without increasing significant detection probability [8]. Therefore, a coefficient $\varphi_{m,n}$ is considered to determine selected sensors, such that: $\varphi_{m,n} = 0$ if sensor *n* does not sense channel *m* and $\varphi_{m,n} = 1$ if sensor *n* senses channel *m*. Also, because every sensor at most can sense a channel for every sensing period, so for every sensor *n* it is assumed that: $\sum_{m=1}^{M} \varphi_{m,n} \leq 1$. We want to select cooperative nodes such that J_m denotes the set of selected sensors which cooperate with each other in sensing channel *m*. Because of limitation of sensors in sensing more than one channel, it is assumed that:

$$\begin{cases} J_m \cap J_{m'} = \emptyset \\ J_m \cup J_{m'} \subset \{1, \dots, N\} \end{cases} \quad \forall m, m' \in \{1, .., M\}, m \neq m' \qquad (7)$$

Table 1. The description of parameters

N	Number of sensors	$d_{m,n}$	Distance between m-th PU to sensor n
M	Number of channels/PUs	$d_{0,n}$	Distance between sensor n to FC
δ	the sensing time	Λ	The PU-signal wavelength
f_s	Nyquist sampling	γ_m	Detector threshold for channel m
$g_{m,n}$	PU-sensor channel gains	$H_{0,m}/H_{1,m}$	Assumption of off/on for m-th PU
s_m	PU signal with variance $\sigma_S{}^2$ over channel m	$P_{d_{m,n}}/P_{f_{m,n}}$	Detection/false alarm probability of sensor n about channel m
$v_{m,n}$	Noise of PU-sensor channel$\sim\mathcal{N}(0,\sigma_v{}^2)$	P_{d_m}/P_{f_m}	Global detection/false alarm prob. about channel m
$\widetilde{g_{m,n}}$	Rayleigh fading over PU-sensor channels	J_m	Selected nodes set for sensing channel m
$z_{n,m}$	Lognormal shadowing with variance σ_z^2 of PU-sensor channels	E_{t-elec}	Energy for the electronic circuits of transmitters
E_s / E_{t_n}	Sensing / Transmission energy	e_{amp}	Amplifying coefficient
EC_n	Energy consumption for sensor n	$H_{0,m}/H_{1,m}$	Assumption of off/on for m-th PU
$E_{0,n}$	Initial energy of sensor n	β_m/α_m	The detection/false alarm prob. limits for channel m
E_n	Residual energy of sensor n	$\mathcal{L}$	The ratio of live sensors to all nodes in lifetime moment

where m and m′ denote two different channels. Therefore, the global detection probability (P_{d_m}) and the global false alarm probability (P_{f_m}) for CSS of channel *m* are respectively written as [20]:

$$P_{d_m} = 1 - \prod_{n \in J_m} (1 - \varphi_{m,n} P_{d_{m,n}}) \qquad (8)$$

$$P_{f_m} = 1 - \prod_{n \in J_m} (1 - \varphi_{m,n} P_{f_{m,n}}) \qquad (9)$$

We want to maximize the lifetime of the multi-channel CSS for a CSN under the global detection and false alarm probabilities constraints. There are different definition for a sensor network lifetime based on the network application [20]. In this paper, the lifetime of a CSN is defined as the time in which a certain percentage of the sensors run out of battery.

Definition 1. The lifetime of a CSN is defined as the moment time that the number of live sensors drops under $\mathcal{L}.N$ where $0 < L \leq 1$, i.e., (1-$\mathcal{L}$).N of sensors have the minimum of energy and cannot sense [20]. ■

As mentioned before, because of battery size and weight limitations of sensors, energy utilization mechanism is an important issue in CSN which imposes a time limit on the network operation life. In order to formulate the lifetime maximization problem, first the needed energy consumption and the residual energy of sensors are calculated. We assume sensing energy of sensor *n*, i.e. $E_s$constant, is the same for all sensors (It is a fair assumption because of equal sensing rate and similar detector of sensors). Also, the energy for transmitting sensor *n* decision to the FC is denoted with E_{t_n}, and it is calculated as [13]:

$$E_{t_n} = E_{t-elec} + e_{amp} . d_{0,n}{}^2 \qquad (10)$$

in which E_{t-elec} is the energy used for the electronic circuits of transmitter, e_{amp} is the amplifying coefficient and $d_{0,n}$ is the distance between sensor n and the FC. Therefore, energy consumption of sensor *n* for participating in CSS of every channel is calculated as [13]:

$$EC_n = E_s + E_{t_n} \qquad (11)$$

3. The Problem with Instantaneous SNR

Our goal is lifetime maximization of a CSN by jointly selecting the appropriate cooperative nodes for sensing each channel, and determining the optimum detector threshold of selected sensors, so that, the constraints on the global detection probability and the global false alarm probability of multi-channel CSS are satisfied. These constraints are assumed to guarantee acceptable sensing quality for all channels. Max-min method is used to solve the problem [21]. In this method, to maximize lifetime, the minimum of residual energy of sensors is maximized, such that the sensors which have larger residual energy and need lower energy consumption are selected for sensing. Therefore, the sensors residual-energy-levels are kept balanced, which leads to extend the network lifetime significantly. On the other hand, the level of detector threshold affects the energy consumption, the detection probability, and the false alarm probability of sensors. Hence, the optimum threshold for sensing every channel, in every duration of network life is found, such that, the global probability of detection and the global probability

of false alarm constraints are satisfied. This multi-channel CSS lifetime maximization is written in an optimization problem framework as follows:

$$\textit{Problem1}: \quad max_{\varphi_{m,n},\ \gamma_m}\{\min_n\{E_n\}\}$$

subject to;

$$E_n \geq \varphi_{m,n}.E_{th} \qquad \forall m,n \qquad (12\text{-}1)$$
$$P_{f_m} - \alpha_m \leq 0 \qquad \forall m \qquad (12\text{-}2)$$
$$\beta_m - P_{d_m} \leq 0 \qquad \forall m \in \{1,\dots,M\} \qquad (12\text{-}3)$$
$$\sum_{m=1}^{M} \varphi_{m,n} - 1 \leq 0 \qquad \forall n \in \{1,\dots,N\} \qquad (12\text{-}4)$$
$$\varphi_{m,n} \in \{0,1\} \qquad \forall m,n \qquad (12\text{-}5)$$

In this problem the minimum of residual energy of sensors is defined as $E_{th} \triangleq \min_n\{E_n\}$. The first constraint shows that the minimum of residual energy of all sensors is E_{th}, and there is at least one sensor with this amount of energy. To guarantee the fair sensing quality, the detection constraints are assumed on every channel. The larger detection probability leads to lower interference with PUs, and the lower false alarm probability means the better usage of free channels. The second constraint states that the global false alarm probability for cooperative sensing of channel *m* should be lower than the desired parameter α_m. The third constraint states that the global detection probability for CSS of channel *m* should be more than the desired parameter β_m. The constraint (12-2) is simplified thanks to the fact that global probability of false alarm is independent of the $SNR_{m,n}$. Therefore, it is concluded from (5), (9), and (12-2) that:

$$|J_m| \leq J_{m\_max} \triangleq \left\lfloor \frac{\ln(1-\alpha_m)}{\ln\left(1-Q\left(\left(\frac{\gamma_m}{\sigma_V^2}-1\right)\sqrt{\delta f_s}\right)\right)} \right\rfloor \qquad (13)$$

For a constant γ_m, if more than J_{m_max} sensors are selected for channel *m*, the false alarm probability constraint for the channel is not satisfied, meanwhile the energy consumption increases due to higher number of selected sensors. Thus, for every level of γ_m, the maximum number of selected cooperative nodes for CSS of the channel is J_{m_max}.

However, Problem1 is a NP-complete problem because of the integer nature of $\varphi_{m,n}$. Finding only sensors under fixed threshold needs an exhaustive search algorithm with complexity order of O(N!) [20]. Since the threshold level of detector is a continuous parameter, finding the optimal solution for the threshold and sensor selection is not possible. The aim of this paper is finding an optimum answer with a lower complexity. Hence, it is assumed that $\varphi_{m,n}$ is a non-negative continuous parameter in order to apply a continuous search algorithm. In fact, this continuous parameter represents the priority of sensor *n* for sensing channel *m*. After solving the problem, $\varphi_{m,n}$ is mapped to '0' or '1', in this way that, the $\varphi_{m,n}$ for sensors with the larger priority, which are selected, are denoted by '1', and for the other nodes are denoted by '0'. Therefore, the standard optimization problem is written as:

$$\textit{Problem2}: \quad max_{\varphi_{m,n},\ \gamma_m}\{E_{th}\}$$

subject to;

$$\varphi_{m,n}\left(E_{th} - \left(E_{0,n} - \sum_{m=1}^{M} \varphi_{m,n} EC_n\right)\right) \leq 0 \qquad \forall m,n \qquad (14\text{-}1)$$

$$\beta_m - \left(1 - \prod_{n \in J_m}\left(1 - \varphi_{m,n}.P_{d_{m,n}}(\gamma_m)\right)\right) \leq 0 \qquad \forall m \qquad (14\text{-}2)$$

$$\sum_{m=1}^{M} \varphi_{m,n} - 1 \leq 0 \qquad \forall n \qquad (14\text{-}3)$$
$$\sum_{n=1}^{N} \varphi_{m,n} - J_{m\_max} \leq 0 \qquad \forall m \qquad (14\text{-}4)$$
$$-\varphi_{m,n} \leq 0 \qquad \forall m,n \qquad (14\text{-}5)$$

The convex optimization method can be used for finding a sub-optimal but efficient solution, although the problem is not convex because of the second constraint. This is a popular method to solve non-convex problems in a simple but efficient way [22]. Because only sensors are selected that their residual energy is larger than E_{th}, the constraint (14-5) is satisfied, and so this constraint is removed. The Lagrange function is formed as follows [22]:

$$L(\varphi_{m,n},\gamma_m,\rho_{m,n},\lambda_m,\eta_n,\xi_m) = E_{th} - \sum_{n,m}\rho_{m,n}\varphi_{m,n}(E_{th} - (E_{0,n} - \sum_{m=1}^{M}\varphi_{m,n}EC_n)) - \sum_m \lambda_m(\beta_m - 1 + \prod_{n\in J_m}(1-\varphi_{m,n}.P_{d_{m,n}}(\gamma_m))) - \sum_n \eta_n(\sum_{m=1}^{M}\varphi_{m,n} - 1) - \sum_m \xi_m(\sum_{n=1}^{N}\varphi_{m,n} - |J_{m\_max}|) \qquad (15)$$

where the Lagrange multipliers $\rho_n, \lambda_m, \eta_n$, and ξ_m are considered for the constraints (14-1), (14-2), (14-3), and (14-4), respectively. The efficient value of $\varphi_{m,n}$ are found by differentiating L with respect to $\varphi_{m,n}$ as [22]:

$$\frac{\partial L}{\partial \varphi_{m,n}} = \lambda_m P_{d_{m,n}} \prod_{\substack{\ell \in J_m \\ \ell \neq n}}(1 - \varphi_{m,\ell}P_{d_{m,\ell}}) - \rho_n(E_{th} - E_{0,n}) - 2\rho_n\varphi_{m,n}EC_n - \eta_n - \xi_m = 0 \qquad (16)$$

Now, the sensors priority to detect channel *m*, are obtained as:

$$\varphi_{m,n} = \frac{-\xi_m - \eta_n - \rho_n(E_{th} - E_{0,n}) + \lambda_m P_{d_{m,n}} \prod_{\substack{\ell \in J_m \\ \ell \neq n}}(1 - \varphi_{m,\ell}P_{d_{m,\ell}})}{2\rho_n EC_n} \qquad (17)$$

We calculate the optimum value of detector threshold of selected sensors, by differentiating L with respect to γ_m, as [22]:

$$\frac{\partial L}{\partial \gamma_m} = \lambda_m \sum_{n=1}^{N}\varphi_{m,n}\sqrt{\frac{\delta f_s}{2\pi\sigma_V^2(2SNR_{m,n}+1)}} . \exp\left(-\frac{\delta f_s}{4SNR_{m,n}+2}\left(\frac{\gamma_m}{\sigma_v^2} - SNR_{m,n} - 1\right)^2\right) . \prod_{\substack{\ell \in J_m \\ \ell \neq n}}(1 - \varphi_{m,\ell}P_{d_{m,\ell}}) = 0 \qquad \forall m \qquad (18)$$

Therefore, the optimum value of γ_m is found from solving the following equation:

$$\sum_{n\in J_m} \varphi_{m,n} \sqrt{\frac{\delta f_s}{2\pi\sigma_V^2(2SNR_{m,n}+1)}} \frac{1}{1-\varphi_{m,n}P_{d_{m,n}}} * \exp\left(-\frac{\delta f_s}{4SNR_{m,n}+2}\left(\frac{\gamma_m}{\sigma_v^2} - SNR_{m,n} - 1\right)^2\right) = 0 \quad (19)$$

To obtain the optimum values of Lagrange multipliers in (17), the complimentary slackness conditions are analyzed [13]. Since the selected nodes are removed from the set of remained nodes, a node is not selected for more than one channel, thus the η_n can be removed from (17). Because ξ_m is independent from sensors number and is a fixed value for every m, therefore, the ξ_m is removed from (17), and just the selected nodes number are checked in order to satisfy the (14-4). The Subgradient method is used for finding the optimal answer of the other Lagrange multipliers in (17). The $\rho_{m,n}$ and the λ_m with step sizes $\ell 1(i) = \frac{C1}{i}$ and $\ell 2(i) = \frac{C2}{i}$ are updated as [22]:

$$\rho_{m,n}(i) = \rho_{m,n}(i-1) + \ell 1(i)\left(E_{th} - E_{0,n} + E_{cn}\right) \quad (20)$$

$$\lambda_m(i) = \lambda_m(i-1) + \ell 2(i)\left(\beta_m - P_{d_m}\right) \quad (21)$$

where "i" is Subgradient iteration number, C1 and C2 are constant values. This algorithm is running until maximum size of changes becomes lower than a small value ϵ, i.e. the algorithm is running while:

$$\max\left(|\lambda_m(i) - \lambda_m(i-1)|, |\rho_{m,n}(i) - \rho_{m,n}(i-1)|\right) \geq \epsilon \quad (22)$$

Now, priority function of sensors for sensing channel *m* is calculated as:

$$\varphi_{m,n} \triangleq \frac{E_{0,n} - E_{th}}{2EC_n} + \frac{\lambda_m P_{d_{m,n}} \prod_{\ell\in J_m, \ell\neq n}\left(1-\varphi_{m,\ell}P_{d_{m,\ell}}\right)}{2\rho_{m,n}E_{cn}} \quad (23)$$

Thus, the sensor with the larger measure of $\varphi_{m,n}$, has the more priority for being selected for cooperative sensing channel *m*. It is noted that the priority function is inversely related to the required energy consumption of sensors for participating in sensing, and is directly related to their residual energy and their detection probability of a channel.

The above solution needs to solve the equation (19) which takes few seconds. Although this time is much shorter than exact search time, it causes a significant delay for sensing in a CSN. On the other hand, the energy consumption of sensors is an increasing function of detector thresholds [17]. Because increasing the threshold level decreases the detection probability of sensors. Therefore, more numbers of sensing nodes is required to satisfy the detection performance which increases the energy consumption. Hence, the minimum threshold is found so that the global probability of detection constraint is satisfied. The threshold optimization problem for every channel is written as:

Problem3: $min\ \{\gamma_m\} \qquad \forall m \in \{1, \dots, M\}$
subject to;

$$\left(1 - \prod_{n\in J_m}\left(1 - \varphi_{m,n}.P_{f_{m,n}}(\gamma_m)\right)\right) - \alpha_m \leq 0 \quad (24\text{-}1)$$

$$\beta_m - \left(1 - \prod_{n\in J_m}\left(1 - \varphi_{m,n}.P_{d_{m,n}}(\gamma_m)\right)\right) \leq 0 \quad (24\text{-}2)$$

, in which (24-1) is replaced with another constraint, the same as (14-4). Direct solving the optimization problem needs to solve (19). However, after sensors were selected, the thresholds minimization can be done by a simple iterative algorithm. The Bisection method is used for finding the optimum thresholds for selected sensors sensing every channel. The threshold levels of different channels are independent; therefore, the detector threshold selection for every channel is a one-dimensional problem which Bisection algorithm is used for determining the dynamic optimum threshold. The details of these algorithms are described in the next section.

4. The Proposed Algorithms

In this section, two algorithms for jointly sensor and detector threshold selection are proposed. Both of them are based on the known instantaneous SNR of sensors. The sensor selection algorithm for extending lifetime of a CSN, with fixed thresholds has been proposed in [20], which we call it as OLBSS (Optimal Lifetime Based Sensor Selection). The pseudo code of this algorithm is plotted in Table 3 of [20]. Here it is extended to the dynamic threshold selection scenario.

In this paper, it is assumed that the PU with more distance from center of the region has more priority for assigning sensors to sense its channel. Our reason for this distance based order is that probably the lower numbers of sensors are located around the PUs which are far from the center. Therefore, there is limited number of sensors with adequate detection probability for being selected for monitoring the PUs. This method is not optimum necessarily, but it provides good solution with low complexity, and it is proper for high number of channels. Also, in all of algorithms, if the problem converged to an acceptable answer that satisfies detection constraints for all channels, the iteration is calculated as successful iteration of lifetime. These algorithms continue until the number of active-sensors is lower than $\mathcal{L}.N$.

4.1 Joint Sensors and Dynamic Thresholds Selection

In every duration of lifetime, at first, with initial thresholds, maximum number of sensing nodes, for every channel is determined. Then, based on the instantaneous SNR of sensors, the detection probability of all sensors for all channels are determined. Now, sensor selection is done the same as OLBSS (save the sensors in S1 matrix). Then, the optimum thresholds are calculated from (19), and with the new measures of thresholds, another sensor selection is done the same as OLBSS (save the new sensors in S2 matrix). If the new selected sensors satisfy the global probability constraint for channel *m*, the loop is repeated. If the global probability constraint is not satisfied for channel *m*, γ_m is increased to the last selection. Finally, the residual energy of selected sensors is updated. The proposed algorithm is called the multi-channel lifetime maximization by jointly sensors and

thresholds selection (JLMTSS). The pseudo code of this algorithm is plotted in Table 2.

4.2 The Reduced Time Joint Sensors and Dynamic Thresholds Selection

An initial feasible set with upper and lower bounds for every $\boldsymbol{\gamma_m}$ is determined. $\mathbf{J_{m\_max}}$ for all channels are determined with initial thresholds which are middle of the feasible sets. Then, based on the thresholds and the instantaneous received SNR of nodes the detection probability of sensors for all the channels are determined. Now, sensor selection is done the same as OLBSS. If the selected sensors for channel *m* satisfied the global probability constraint, the $\boldsymbol{\gamma_m}$ decreases, otherwise the $\boldsymbol{\gamma_m}$ increases. This loop is repeated until the terminating criterion of Bisection algorithm is met. Then residual energy of sensors is updated. This algorithm is called the first reduced time multi-channel lifetime maximization by jointly sensors and thresholds selection (RJLMTSS1). The pseudo code of this algorithm is plotted in Table3.

TABLE 2 JLMTSS1 ALGORITHM

Step1 and Step2 are done the same as OLBSS,([20]**, Table 2) and save Set1 in S1.**
Step3: **for** n=1:N
for m=1:M
if there is node n in m-th row of S1, $\varphi_{m,n}$=1;
else $\varphi_{m,n} = 0$;
end
end
end
Calculate optimum thresholds from Eq.(19).
Step4: Repeat Step1 and Step2 with the new thresholds, and save the new Set1 in S2.
for m=1:M
$P_{d_m} = 1$
for j=1: J_{m_max}
if $(S2(m,j) \neq 0)$
ns= $S2(m,j)$ & $P_{d_m} = 1 - (P_{d_m} * (1 - P_{d_{m,ns}}))$
end
end
end
Step5: **if** $(P_{d_m} \geq \beta_m)$ clear S1, save S2 in S1, clear S2 and go to step3
else S1 are the selected nodes and do step 3 of OLBSS.
end

TABLE 3 RJLMTSS1 ALGORITHM

Step0 is done the same as OLBSS. The feasible set for every γ_m is determined.
Step2: **for** m=1:M $\boldsymbol{\gamma_m = \frac{\gamma_{m_{min}} + \gamma_{m_{max}}}{2}}$ **end**
Select nodes for every channel the same as step1 and step2 in OLBSS
Step3: **if** $(P_{d_m} \geq \beta_m)$
$\boldsymbol{\gamma_{m_{min}} = \gamma_m}$
else $\boldsymbol{\gamma_{m_{max}} = \gamma_m}$
end
Step4: **if max**$(\boldsymbol{\gamma_{m_{max}} - \gamma_{m_{min}}}) < \varepsilon$
Do step3 of OLBSS
else Go to step2**.**
end

Table 2. The values of simulation parameters

$\mathcal{L} = 0.25$	$E_{0,n} = 0.2$ mJ	$E_{t-elec} = 80$ nJ	σ_z^2=3db
$\alpha_m = 0.1$	$E_s = 190$ nJ	$e_{amp} = 40.4$ pJ/m^2	p_t=20mW
$\beta_m = 0.9$	$\sigma_0^2 = 10^{-11}$W	$f_c = 2.45$ GHZ	M=8

5. The problem with average SNR

Since calculating the instantaneous SNR is difficult, in this section the joint sensors and thresholds selection algorithm for multi-channel CSS is extended to the case that the FC knows only the average SNR of sensors. In this case, the false alarm probability of sensors is the same as (5) because it does not depends on the SNR of sensors. Therefore, the average global probability of false alarm for this problem is the same as (9), but the detection probability of sensors depends on their received SNR. For the case that the FC knows only the average SNR information, the average detection probability is used for sensors and thresholds selection. The average detection probability is calculated as [13]:

$$\overline{P_{d_{m,n}}} = \int_0^\infty P_{d_{m,n}} . f_{\varpi_{m,n}}(\varpi_{m,n}) . d\varpi_{m,n} \quad (25)$$

where $f_{\varpi_{m,n}}(\varpi_{m,n})$ denotes the probability density function (PDF) of the received SNR of sensor *n* from m-th PU ($SNR_{m,n} \triangleq \varpi_{m,n}$). Under the assumed channel gain in (3), the PDF is an exponential distribution with the average as [17]:

$$\overline{SNR}_{m,n} \triangleq \overline{\varpi_{m,n}} = \frac{p_t}{\sigma_v^2}\left(\frac{\Lambda}{4\pi d_{m,n}}\right)^2 . \exp\left(\frac{(\ln 9)^2 \sigma_Z^2}{220}\right) \quad (26)$$

Thus, the average detection probability is calculated as:

$$\overline{P_{d_{m,n}}} = \int_0^\infty Q\left(\left(\frac{\gamma_m}{\sigma_v^2} - \varpi_{m,n} - 1\right)\sqrt{\frac{\delta f_s}{2\varpi_{m,n}+1}}\right) . \frac{1}{\overline{\varpi_{m,n}}} \exp\left(\frac{-\varpi_{m,n}}{\overline{\varpi_{m,n}}}\right) . d\varpi_{m,n} \quad (27)$$

which the closed form of $\overline{P_{d_{m,n}}}$ is calculated as [25]:

$$\overline{P_{d_{m,n}}} = \frac{1}{2\overline{\varpi_{m,n}}} \frac{\exp\left(\sqrt{\delta f_s}\left(\frac{\gamma_m}{\sigma_v^2} - 1\right)\left(\sqrt{\frac{\delta f_s}{7} + \frac{1}{2\overline{\varpi_{m,n}}}} - \sqrt{\frac{\delta f_s}{7}}\right)\right)}{2\sqrt{\frac{\delta f_s}{7} + \frac{1}{2\overline{\varpi_{m,n}}}}\left(\sqrt{\frac{\delta f_s}{7} + \frac{1}{2\overline{\varpi_{m,n}}}} - \sqrt{\frac{\delta f_s}{7}}\right)} \quad (28)$$

Then, the average global probability of detection is a function of average SNR of sensors as following:

$$\overline{P_{d_m}} = 1 - \prod_{n \in J_m} (1 - \varphi_{m,n} \overline{P_{d_{m,n}}}) \quad (29)$$

Similar to the RJLTMSS1 algorithm, the optimization problem is solved with constraints on the average global detection probability. We call the investigation of RJLTMSS1 under the scenario as RJLMTSS2, which is compared to show that the proposed algorithm can be extended to realistic scenarios.

6. Simulation results

In this section, the algorithms are numerically evaluated through computer simulations using MATLAB. The Monte-Carlo method is used with 5000 number of iterations. An square region with $200m$ length is assumed. An FC is located in the center of the region. *N* sensors and *M* PUs are distributed identically in this region. The IEEE *802.15.4/Zigbee* is used for the

cognitive sensors [26]. The simulation parameters are presented in Table 2. The performance of the proposed algorithms is compared with the following algorithms:

- *Detection based serially sensor selection and thresholds setting:* First this algorithm selects sensors based on the detection probability of nodes, and then determines optimum detector thresholds for the selected sensors. This scheme is a conclusion from [18] by a different object. In that work, in multi-channel CSS with the aim at throughput maximization, first clustering all the sensors was done, then the optimum thresholds for the sensors was determined such that the detection and false alarm probability constraints are satisfied. The lifetime maximization by serially sensors and thresholds selection algorithm is called as LMSST.
- *Random based serially sensor selection and thresholds setting:* This algorithm is compared because of its lower order of complexity respect with the proposed algorithms. First the sensors are selected randomly. Then, a random detector threshold, from the feasible set of γ_m, is determined for channel m. This algorithm is called the random sensor and threshold selection algorithm (RTSS).

One of the metrics for efficiency of algorithms is the rate of satisfying the problem constraints. A success metric is defined as the ratio of the successful-iterations-number to the maximum-iterations-number. A successful iteration is iteration that an algorithm finds answer which satisfies all the constraints. Also, for better scaling, the success percentage is normalized on the basis of the maximum iterations between all the simulated algorithms. In **Error! Reference source not found.**, the success ratio of the both algorithms, that are proposed based on the known instantaneous SNR, i.e. the JLMTSS and RJLMTSS1 are compared at different total number of sensors. The higher number of sensors leads to higher success ratio for both algorithms, because there are more proper sensors for being selected. It is concluded that the success ratio of JLMTSS is higher than RJLMTSS1, because JLMTSS finds the optimum thresholds for selected sensors by solving the equation (19), but the RJLMTSS1 finds a suboptimum threshold for sensing every channel via a reduced complexity algorithm. This superior performance of JLMTSS is obtained in exchange for longer processing time. In **Error! Reference source not found.**, the lack of instantaneous SNR effect of sensors is presented by comparing the success ratio of the RJLMTSS1 and RJLMTSS2. This plot shows that knowing the instantaneous SNR leads to better selection of sensors and thresholds, because RJLMTSS2 selects more sensors than RJLMTSS1 to satisfy the detection probability constraint. It is noted that, since the procedures of these algorithms are similar, the changes in the success ratios versus sensors number are almost the same.

Error! Reference source not found. compares the success ratio of the RJLMTSS1 with the benchmark methods. It is obvious that, the higher number of sensors leads to higher success ratio for all the algorithms. The proposed algorithm has the top success ratio, which it leads to successful response in more than 95% of iterations. The LMSST algorithm which serially selects sensors and thresholds leads to the second highest success ratio. Because in LMSST the sensors are selected based on their detection probability, in which the consumption and residual energy of sensors are neglected. Also, non-jointly sensors and thresholds selection is another reason of the lower success rate of LMSST. The OLBSS algorithm which only selects suitable sensors with a predefined-fixed-threshold for sensing the channels has the third highest success ratio. This algorithm does not find efficient thresholds for sensors; therefore more sensors are selected for satisfying the detection constraints. The RTSS algorithm has the lowest success ratio. This algorithm has lower order of complexity but cannot efficiently extend the network lifetime.

In **Error! Reference source not found.**, the average number of selected sensors for sensing the channels is plotted. When the total number of sensors increases, the problem constraints are satisfied with lower number of selected sensors, because number of sensors with higher detection probability increases. This plot shows that the proposed algorithms use the least number of sensors. However, the JLMTSS finds optimal thresholds for the selected sensors which increases the detection probability of sensors, and therefore, it satisfies the detection constraints with lower number of sensors. RJLMTSS1 finds sub-optimal thresholds for the selected sensors, but its performance is more effective than other benchmark methods. LMTSS is the third, which it is concluded from ignoring the energy conservation in sensor selection and non-jointly sensors and thresholds selection. This algorithm selects sensors with higher detection probability that needs the lowest number of selected sensors at first glance. However this metric amount is averaged over the total number of iterations. It is noted that the sensors that has the highest detection probability may require a lot of energy to send their decision bit to the FC. So the selected sensors in the early iterations of network lifetime are selected frequently, and therefore the sensors batteries drain faster. Hence, on average, the number of selected sensors of LMSST is higher than the proposed algorithms. The OLBSS algorithm is the forth because it does not set the efficient threshold levels for sensor`s detector, therefore more sensors will be selected for satisfying the detection constraints. Also, the effect of knowing the instantaneous SNR on the number of selected sensors is shown in this plot by comparing the results of RJLMTSS2 with other algorithms.

Note that all the algorithms use the instantaneous SNR except for RJLMTSS2. Although, estimating the instantaneous SNR is difficult, but using the average SNR necessitate us to select more sensors for satisfying the detection constraints. The RTSS requires the highest number of sensors for the multi-channel CSS because of

ignoring the detection probability of selected sensors, and not setting efficient thresholds for detector. In **Error! Reference source not found.**, the average energy consumption for every sensing period of multi-channel CSS is presented. This metric for every algorithm is averaged on the all iterations of the network lifetime. The proposed algorithms provide the least energy consumption, because they jointly select sensors and thresholds. When the total number of sensors increases, the average measure of energy consumption reduces for all algorithms, because number of sensors with higher detection probability increases, and therefore, lower number of sensors are required for satisfying the detection constraints.

In table 3, the average time for finding sensors and detector thresholds for every iteration of multi-channel CSS is shown, meanwhile the successful lifetime of the algorithms is compared. It is noted that the optimal method for finding sensors and determining optimal thresholds is not possible to compare. The JLMTSS needs the longest time and the RTSS needs the shortest time to find answer. But, RTSS consumes more energy and it leads to shorter lifetime for the network. Also, most of the times, solution of this algorithm is not accepted because it does not satisfy the detection quality constraints. The RJLMTSS1 needs lower time to find the efficient solution for the problem than the JLMTSS. The RJLMTSS2 needs processing time the same as RJLMTSS1, because their procedures are similar. The LMTSS and OLBSS need shorter time than the proposed algorithms, but their solutions are not as efficiency as the proposed algorithms.

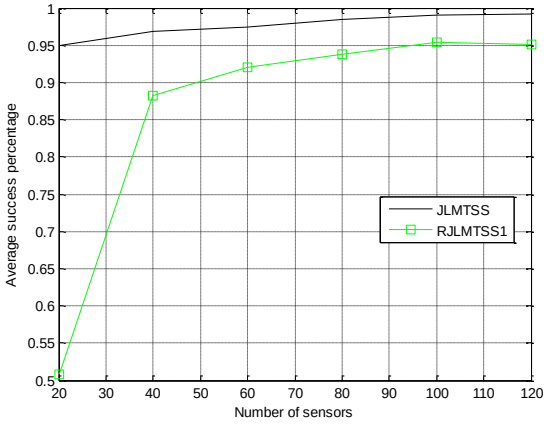

Fig. 3. The success ratio versus the total number of sensors.

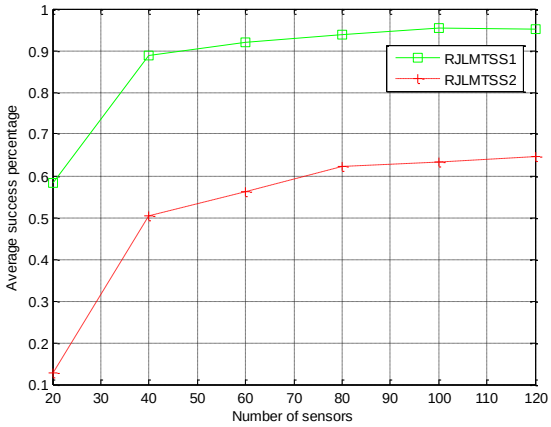

Fig. 4. The success ratio versus the total number of sensors.

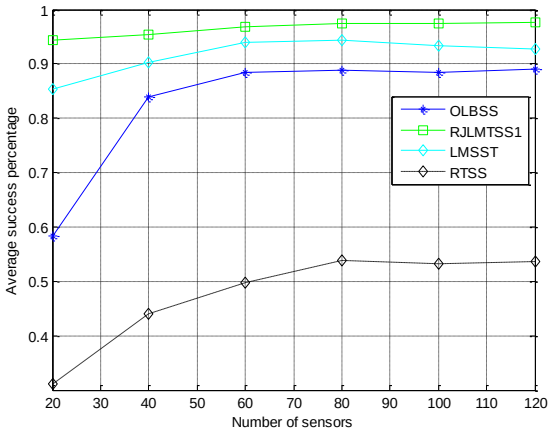

Fig. 5. The success ratio versus the total number of sensors.

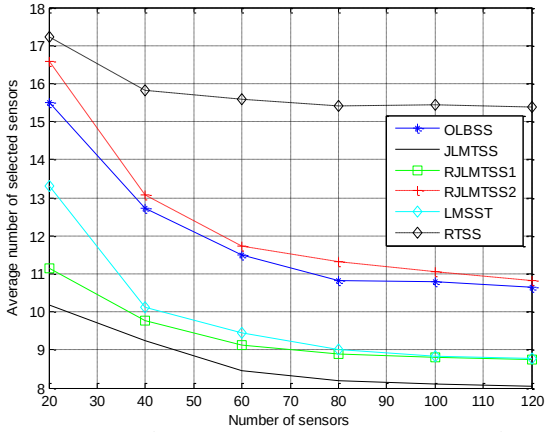

Fig. 6. The number of selected sensors versus the total number of sensors.

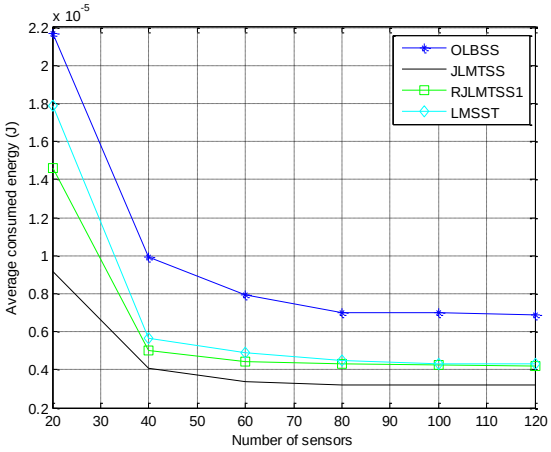

Fig. 7. The average energy consumption for multi-channel CSS versus the total number of sensors.

Table 3. The average time and successful lifetime comparison

The average time to find answer			The average successful lifetime	
Number of sensors	60	120	60	120
JLMTSS	37.722 s	73.174 s	2312	4616
RJLMTSS1	1.0226 s	4.3317 s	2171	4429
LMSST	0.4440 s	1.7484 s	2038	4115
OLBSS	0.1891 s	0.7546 s	1971	4004
RTSS	0.079s	0.841s	1108	2306

7. Conclusion

In CSNs usually apply the tiny and low-cost sensors. These sensors cannot simultaneously sense more than one channel because they do not have high-speed ADCs and high-energy. In order to overcome this problem, in this paper it was proposed two novel algorithms that maximize the network lifetime by selecting both the cooperative sensors and their detector threshold. First algorithm applies the known instantaneous SNR and obtains the proper detector thresholds by solving an equation for every channel. In the second algorithm in order to reduce the complexity of the problem it is proposed the Bisection method for determining detector thresholds. In the first algorithm, i.e. JLMTSS, the detector thresholds are optimized for cooperative sensors, based on the known instantaneous received SNR of sensors. This algorithm provides the longest lifetime for the CSN, but it is complicated and needs longest time to find the optimal solution. Of course this time is very short in compare with the exact search algorithm which finds the optimal sensors and thresholds. The second algorithm, i.e. RJLMTSS1, finds efficient solution at a processing time which is applicable, while its performance is relatively good. From table 2 it is concluded that its performance is *94%* of the JLMTSS algorithm when its processing time is *0.05%* of the JLMTSS processing time (when the total number of sensors is *120*). knowing the instantaneous SNR is difficult so we have investigated the performance of the second algorithm by average value of SNR. It was concluded that knowing the instantaneous SNR leads to better performance. Also, the proposed algorithms were compared with the other benchmark methods that can be performed in similar conditions. The comparisons showed that the proposed algorithms extend lifetime of a CSN with a good rate. The effect of thresholds setting on the energy conservation of a CSN was studied, which concluded that it can improve the network successful lifetime more than *10%* (*N=120*, comparison between OLBSS and RJLMTSS1). Also, jointly sensors and thresholds selection based via max-min method improves the network lifetime more than *7.6%* respect with serially sensors and thresholds selection based on the detection probability of sensors (*N=120*, comparison between LMSST and RJLMTSS1). The comparison between the proposed algorithms with a low-complexity algorithm showed that the proposed algorithms improve the network lifetime more than *90%* respect with the random sensors and thresholds selection algorithm (*N=120*).

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Analysis of Imperfect Space Channel for the Next Generation Satellite Networks

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Received: 21/Feb/2017 Revised: 16/Sep/2017 Accepted: 01/Jan/2018

Abstract

An efficient space data management is imperative in guaranteeing the best performance with a fair distribution of next generation satellite networks. Therefore, one of the major challenges to implement this kind of future satellite networks is evaluation any untrusted error for the best quality of service (QoS). In this regard, bit error rate (BER) criteria based on the type of space channel which it can be defined prefect or imperfect state between one or more satellites and terrestrial infrastructures seems to be an important subject for space communication. In this paper, the authors provide a bandwidth sharing algorithm for a proposed future heterogeneous satellite networks. This structure can have many satellites in different orbits beside terrestrial equipment having many antennas. In this paper to evaluate this system model, the coverage probability and space capacity based on input parameters such as path loss and signal to noise ratio (SNR) has been analyzed. Also, the bit error rate for a Multi-Input-Multi-Output (MIMO) satellite network based on imperfect channel estimation is simulated based on quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK) digital modulations which input parameters are error rate due to imperfect channel estimation and the number of antennas. Finally, two digital modulation compared together based on error rate changes.

Keywords: Satellite Communication; Small Cell; Frequency Reuse; Bandwidth Sharing; Imperfect Channel.

1. Introduction

Nowadays, There is a huge traffic demand from Very High Throughput Satellite systems (VHTS) to provide non delay sensitive services such as *Mobile-satellite* service having more secure and low delay based on new generation satellite networks such as fifth generation (5G) road map [1]. Most of space players have more endeavor to provide new space structures based on many satellites in different orbits look like satellite constellations along with terrestrial infrastructures look like base station which is well known Hybrid satellite-terrestrial networks to more coverage and capacity in anywhere and anytime[2]-[3]. This new structures in space part, has one or many satellites in different orbits such as low earth orbit (LEO) and medium earth orbit (MEO) which are called non-geostationary orbit (Non-GSO) or GEO that is called GSO. Based on orbital height, there are many opportunities to obtain efficiency in quality of space service. Moreover, this kind of structure can extend backhaul space services such as terrestrial mobile network. Thus, the integration of terrestrial infrastructures with many satellites in different orbits is attractive subject in future space research. With development Fifth Generation(5G), most of wireless communication systems expose with different challenges such as raising throughput and capacity, decreasing delay and latency, increasing coverage and reliability, causing seamless connection in anytime and anywhere based on 5G propagandas. In this reason, telecommunication industry must try to use satellite systems beside other infrastructures to provide more services to end space users [4]-[5].

Need for next generation satellite networks which have numerous antennas to communicate space data are very imperative in the development of space communication with the least error available due to environmental conditions in space channel between satellites and terrestrial equipment. To address this subject, several scenarios have been proposed based on space channel statistical status. One of them is perfect space channel which all of information in channel receiver is known [6]-[7]. A satellite system with prefect space channel has the following advantages based on the number of small cells:

1. The downlink and uplink power from the satellite is divided among small cells, and the bandwidth remains constant for each small cell. Ultimately, the total bandwidth increases as the number of small cells.

2. There will be a wide coverage by the satellite system following the replacement of several small cells [8].

In satellite systems with different antennas for the uplink or downlink, all of the receivers can be divided into small cells to take satellite services from one or many small cells with respect interference management among them. In this scenario, each antenna from the satellite can provide a suitable space link to each small cell which insert many users in them. Consequently, space industry needs a suitable solution to divide space resources

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between small cells which are covered by a satellite system [9]. In next generation satellite networks with long life time in space, it is very important to check the situation of traffic data between satellite and small cells based on resource conditions such as power and bandwidth. Therefore, a new algorithm is provided in [10], some new algorithm management for the provision of services is provided in [11]. Moreover, a new algorithm based on maximum/minimum signal to noise plus noise ratio and optimized data allocation is proposed in [12]. This algorithm can surmount the bit error rate of satellite systems when the number of antennas is increased on the side of the satellite or the side of the cell. To this end, it was analyzed and simulated based on the path loss factor. In [13], a solution for resource management based on the traffic level between the satellite system and the small cell was proposed. In [14], a new remedy for satellite systems was provided based on traffic demand. A new method based on frequency reuse in the achievement of high data rate in satellites was provided in [15]. In this paper, for a heterogeneous satellite network (HSN) having one or many satellites in different orbits, there is a line of side (LoS) space channel from any satellite to any terrestrial equipment which effects from space weather conditions. Firstly, based on environmental conditions may not be a prefect statistical status to evaluate performance space link. Secondly, space channel estimation for an imperfect space channel was computed to evaluate error level in each satellite system. For these evaluations, it is very important to evaluate a typical satellite network for the first step. Therefore, the main contribution in this paper is the introduction of a proposed model system which includes one or many satellite systems in different orbits beside terrestrial infrastructures such as ground stations providing based on the new bandwidth sharing algorithm. Also, the efficiency of the space link between satellites and ground stations for resource management which is critical point for this new kind of HSN is simulated by two types of digital modulation based on space recommendations. Finally, these digital modulations are compared with each other.

The rest of this paper is made up of the following sections. In Section II, the system model and the main formulations were proposed. In Section III, the new bandwidth sharing algorithm was supplied. In Sections IV, bit error rate equation based imperfect channels was computed. In Section V, simulation results based on proposed system model and desired input parameters were provided. Finally, Section VI, conclusion is drawn based on the research paper which is used MATLAB software for this reason.

2. Heterogeneous Satellite Network Model

The proposed heterogeneous satellite network is made up of two satellites, which have many antennas to transmit space (Orthogonal Frequency Division Multiple) OFDM data. In this paper, the effect of the enhancement of the number of antenna is taken into consideration. Consequently, M is the number of the transmitter's antennas at the side of the satellite(s) and N is the number of the receiver's antennas at the side of the small cell for any user. According to space requirement in (European Cooperation for Space Standardization) ECSS documents, the proposed system model was evaluated by using of two digital modulations which is known QAM and QPSK. Also, bit error rate was formulated by two digital modulations taking into consideration the space channel statistic status among satellite(s) and ground station(s). And finally, the estimation error was considered in the performance analysis of the proposed model system. In this system model is assumed, the satellite systems can be employed in GEO and LEO which are shown in Fig.1. In addition, the carrier frequency for this structure was assumed to be Ku, which is used to provide any space services. As seen in Fig.1, each satellite is supposed to has many antennas at the side of the satellite using to cover small cells. In this scenario, each antenna should have a minimum bandwidth to provide satellite service for any user in small cell.

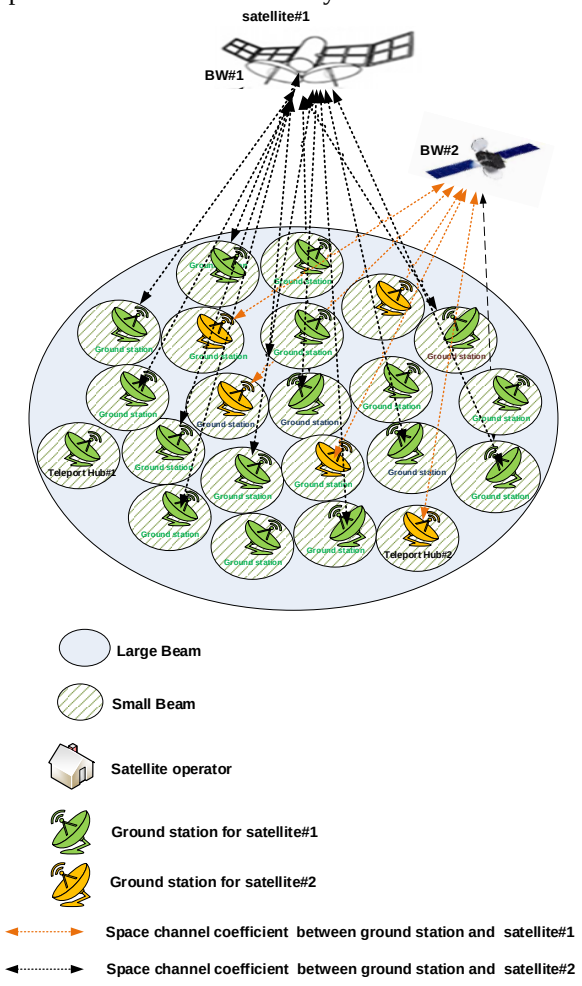

Fig. 1. Heterogeneous satellite networks

As well as, in each satellite system, one of the error criteria is the lack of communication data from satellite in a given small cell. So, there should be a specific benchmark to evaluate coverage area which it is

important to dedicate different types of users such. For this reason, coverage probability (CP) of the satellite system was simulated as the SNR. Also, this parameter was found to be larger than a specific threshold level SNR with respect to the path loss factor e such as space weather conditions (rain attenuation) causing unsuitable condition (imperfect space channel) for satellite systems [16]. Note that the coverage probability is independent of the number of antennas on the side of the satellite or cell. When the threshold SNR is greater than the first value, coverage probability in closed form can be computed (1) [17]:

$$CP = \frac{e \times \sin(\pi / e)}{\pi \times SNR^{1/e}} \quad (1)$$

The coverage probability for each small cell in the satellite system is presented in Fig.2. In Fig. 2, path loss factor must be greater than the second value because the coverage probability in the satellite system has a better performance than the third and fourth values in the coverage probability. This is due to the fact that noise and propagation delay have less effect in channels between the satellite and ground cells in the investigated scenario.

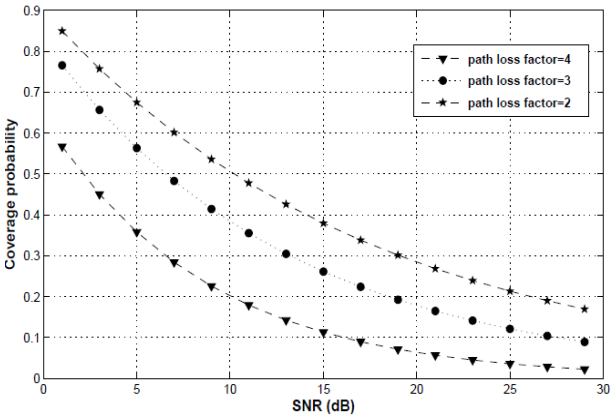

Fig. 2. Comparison of coverage probability versus different path losses.

3. A Mathematical Bandwidth Sharing Algorithm

Due to the increasing number of users to receive any satellite service especially in 5G road map, the Necessity of existence algorithms to resource managements such as power or bandwidth in these new types of satellite network seems to be important. In this regard, a bandwidth sharing algorithm is presented in this paper.

In this paper, we assumed that the minimum and initial bandwidth of the ith small cell for satellite system is $\mathbf{B_{min}}$ and $\mathbf{B_{initial}}$ based on space service level agreements (SSLAs). In addition, the total bandwidth for satellite was $\mathbf{B_{total}}$ and **K** was the number of small cell in the investigated scenario. Table I. shows a new bandwidth sharing formulation in the satellite system based on priority small cells which was specified in SSLA. In addition the bandwidth sharing management problem, frequency reuse factor is very important for designing satellite system to enhance capacity allocation.

Table 1. Bandwidth management HSN between small cells

```
clc
clearall
B_total = input('Total _bandwidth');
B_initial = input('Initial _bandwidth');
B_min = input('Minimum _bandwidth');
if  B_total ≥ B_initial
B_extra = B_total - B_initial ;
else if
B_extra = 0;
end
end
If  B_min  B_initial   # For each beam in satellite network
B'_min = B_min - B_initial ;  # Determination required bandwidth based on[B_min , B_initial]
end
B'_extra = B_extra - B'_min ;  # Evaluation the extra required bandwidth based on[B_extra , B'_min]
if  B'_extra ≥ 0
B'_initial = B'_extra + B_min ;
end
```

4. Bit Error Rate Computation Based on Imperfect Space Channel

As shown in Fig.1, on the basis of the prefect channel between satellite and ground cells, it was assumed that M-QAM and M-PSK had **M ×N + 1** degrees of freedom, where the weight is a function of the number of transmitter's antennas **M** on the side of the satellite and the number of receiver's antennas **N** on the side of the ground station. In this model of transmission, each antenna in two sides of model will be able to send or receive data to each other based on matrix formats. As a result, received signal R can be obtained by equation (2) which will be explained in the following. The prefect channel between the satellite and ground cell was modeled by a LoS channel and can be obtained by a matrix **H** with **M ×N** order and a zero mean and variance unit value. Each entry of matrix **H** is shown in $\mathbf{H}_{m\times n}$. $\mathbf{H}_{m\times n}$ represents the space channel gained between the mth receiver antenna at the side of the ground cell and the nth transmitter antenna at the side of the satellite. In addition, the received signal vector r can be given as [13], where $\mathbf{f_c}$ denotes the carrier frequency, C_0 is the speed of light, **d** is the distance between the transmitter antenna and receiver antenna and σ^2 is the additive white Gaussian noise. Moreover, the amount of rain attenuation was represented as $\mathbf{A_{Rain\ attenuation}}$ which was imposed to coverage probability, **S** is transmitter symbols based on matrix form from the side of the ground station and I is the unique matrix. Moreover, $a_{m\times n}$ denotes the space channel coefficients between the transmitter antenna and receiver antenna, which can be denoted as follows (2):

$$\mathbf{R}_{m\times 1}=\mathbf{H}_{m\times n}\times\mathbf{S}_{n\times 1}+\mathbf{n}_{m\times 1},$$
$$\mathbf{H}_{m\times n}=\mathbf{a}_{m\times n}\times\exp\left(-j\times\frac{2\times\pi\times f_c}{C_0}\times d\right)$$
$$\times\exp\left(\frac{-A_{Rain-attenuation}}{10}\right), \quad (2)$$
$$\mathbf{a}_{m\times n}=\frac{C_0}{4\times\pi\times f_c\times d},$$
$$\mathbf{n}_{m\times 1}=N(0,\sigma^2\times\mathbf{I}_{m\times 1}).$$

In this formulation, some small cells had more bandwidth. Consequently, bandwidth management for capacity allocation is very important. In this section [19]-[21], by recognizing the space channel, the BER expression for M-QAM and M-PSK was formulated (3-4):

$$BER_{M-QAM}=\frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left(\frac{1}{2}\times(1-\mu_0)\right)^{N-M+1}\times$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_0)\right]^K+$$
$$\frac{2\times(\sqrt{M}-1)}{\sqrt{M}\times\log_2(\sqrt{M})}\times\left[\frac{1}{2}\times(1-\mu_1)\right]^{N-M+1}\times$$
$$\sum_{K=0}^{N-M}\binom{N-M+K}{K}\times\left[\frac{1}{2}\times(1+\mu_1)\right]^K, \quad (3)$$

$$BER_{M-PSK}=\frac{2}{\max\times(\log_2 M,2)}\times$$
$$\sum_{K=0}^{\min(2,|M/4)|}\left(\left[\frac{1}{2}\times(1-\mu_K)\right]^{N-M+1}\times\sum_{L=0}^{N-M}\binom{N-M+L}{L}\times\left[\frac{1}{2}\times(1+\mu_K)\right]^L\right)\times \quad (4)$$

Where 'μ_i' is as follow:

$$\mu_i=\sqrt{\frac{SNR\times\sin^2((2\times i-1)\times\pi/M)}{1+SNR\times\sin^2((2\times i-1)\times\pi/M)}}. \quad (5)$$

Unfortunately, in practice satellite systems, perfect channel may not be available. Consequently, the effect of channel error based on path loss on the performance of satellite networks must be investigated. This was achieved by modeling the estimation error as independent complex Gaussian random variables. In this paper, we estimated the imperfect space channel and surveyed the performance of receivers based on Zero Forcing (ZF) estimation algorithm. Also, all of BER formulations are obtained in closed-form.

Thereafter, the BER for satellite systems with M-QAM and M-PSK modulated signals were derived in the closed form. Based on assumption, the received signal vector r' can be written as:

$$\mathbf{r}'_{m\times 1}=\mathbf{H}'_{m\times n}\times\mathbf{S}_{n\times 1}+\mathbf{n}_{m\times 1},$$
$$\mathbf{H}'_{m\times n}=\mathbf{H}_{m\times n}+\mathbf{e}_{m\times n}. \quad (6)$$

Now, we supposed that $\mathbf{H}'_{m\times n}$ is the non-suitable space channel, **n** is the white Gaussian noise and e is the path loss factor which is caused error in space link. This parameter does not correlate with $\mathbf{H}_{m\times n}$. The correlation coefficient ρ between the prefect and imperfect channels based on e is given by:

$$\rho=\frac{E\left(\mathbf{H}_{m\times n}-(\mathbf{H}_{m\times n}')^*\right)}{\sqrt{E\left[\mathbf{H}_{m\times n}{}^2\right]\times E\left[(\mathbf{H}_{m\times n}')^{*2}\right]}}=\frac{1}{\sqrt{1+\mathbf{e}^2}} \quad (7)$$

E(:) is statistical mean for each variable. Therefore, the SNR distribution based on e can be obtained as follows:

$$SNR(\mathbf{e})=\frac{SNR}{\left[1+(\mathbf{e}^2\times M\times s/\mathrm{E}\left(n^2\right)\right]} \quad (8)$$

By manipulation and making some changes in (9), the μ_i can obtain as follows:

$$\mu_i=\sqrt{\frac{SNR(\mathbf{e})\times\sin^2((2\times i-1)\times\pi/M)}{1+SNR(\mathbf{e})\times\sin^2((2\times i-1)\times\pi/M)}}. \quad (9)$$

5. Simulation Results

In this paper, in order to carry out the simulation process, a heterogeneous satellite network was provided. Also, to simulate input parameters of the system model were presented in Table 2. The allocated bandwidth of the i[th] small cell with/without bandwidth sharing algorithm was compared as seen in Fig.3. As is clear, in some small cells such as third, sixth and eighth small cells, there is better performance because these small cells provide extra bandwidth to other small cells based on sharing bandwidth algorithm to allocate bandwidth properly which is provided in section III.

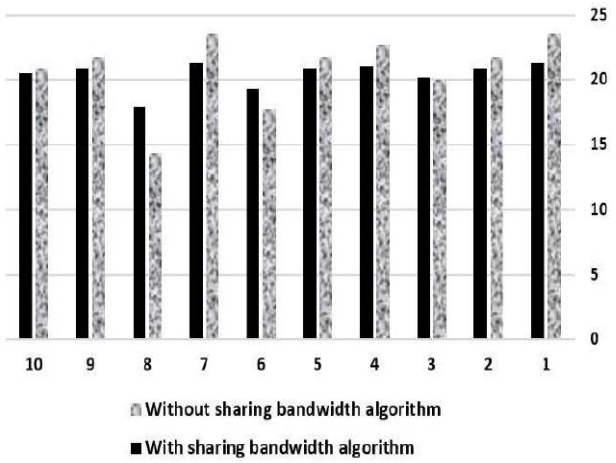

Fig. 3. Compare between with/without bandwidth sharing algorithms for the i[th] small cell.

In Figs. 4 and 5, the BER performance of QPSK and QAM was investigated for imperfect channel with M= 4, N = 10 for e = [0; 10; 20; 30; 40; 50] percentages using the channel estimation error model in (9).

Table 2. Input Parameters of the HSN

Definition Parameter	Value
Satellite frequency ($\mathbf{f_c}$)	11.0175 GHz-14.125 GHz
Distance satellite from earth (**d**)	36000 Km
Total Bandwidth of each small cell($\mathbf{B_{Total}}$)	530 MHz
Minimum Bandwidth of each small cell ($\mathbf{B_{min}}$)	36 MHz
Initial Bandwidth of ten spot small cells($\mathbf{B_{initt}}$)	[36,45,55,40,45,72,36,106,45,50] MHz
Signal to Noise Ratio(**SNR**)	From 0 to 30 by 5 step size
Digital modulation type	QAM and QPSK
Number of small cells	10
Number of receiver antennas (**N**)	10
Number of transmitter antennas(**M**)	4

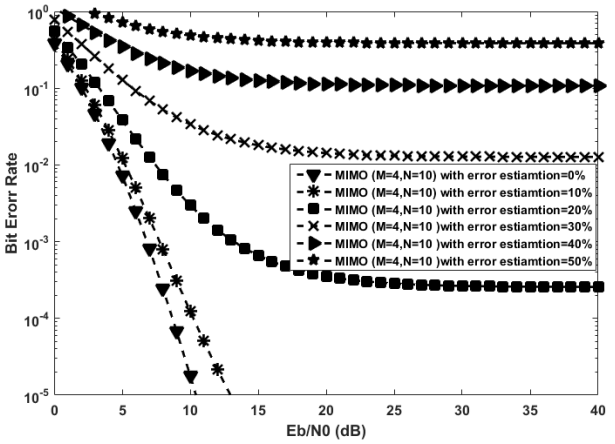

Fig. 4. BER performance of QPSK versus SNR (dB) based on path loss factor (e), [M=4, N = 10,8,6,4].

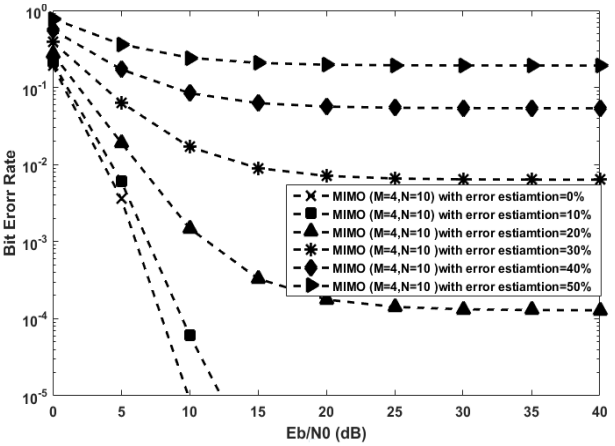

Fig. 5. BER performance of QAM versus SNR (dB) based on based on path loss factor (e), [(M=4, N = 10)].

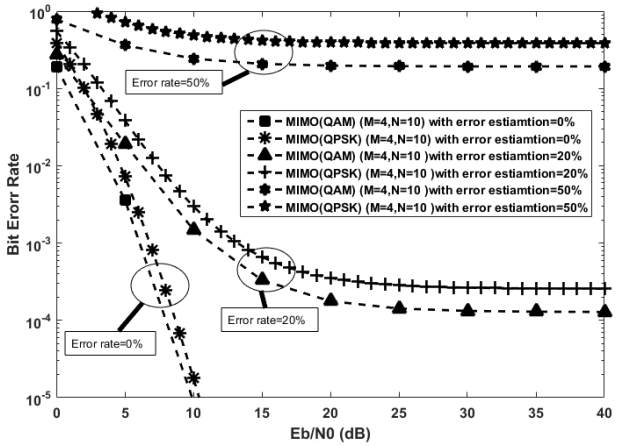

Fig. 6. Comparison BER between of QAM and QPSK versus SNR (dB) based on based on path loss factor (e), [(M=4, N = 10)].

As seen in these figures, it can be concluded that bit error rate increases with an increase in error estimation variance and QAM is better than QPSK based on the increase in the estimation error variance. Also, Under Consideration all the input parameters such as the number of antenna in satellite or ground station side, it can be concluded that the probability of BER in the QAM is less than QPSK.[20].

6. Conclusion

In this paper, first of all, a proposed HSN structure was provided which is considered by space industry to provide 5G requirements. In this way, a new algorithm to manage the space bandwidth in satellite systems was provided based on mathematical form. Also, based on space recommendations, HSN was simulated based on BER for both the QAM and QPSK digital modulation which is two types of recommended digital modulations in satellite systems. For this purpose, two perfect and imperfect space channels based on ECSS was compared together. As seen from the simulation results, an increase in the number of transmitter antennas in satellite systems precipitated an enhancement in capacity which is suitable to 5G road map. Furthermore, it should also be mentioned that the trade-off between the coverage probability and the BER of heterogeneous satellite network is important. Consequently, it is very important that next generation HSN has comprehensive review in space channel condition and resource management to reach high efficiency in future space telecommunication.

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Representing a Model to Measure Absorbency of Information Technology in Small and Medium Sized Enterprises

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Received: 17/Jul/2017 Revised: 21/Oct/2017 Accepted: 11/Dec/2017

Abstract

With rapid development of information technology (IT) and further deepening of informationization construction, more and more enterprises have realized the strategic value of IT and made great investments in it. However, during the IT implementation process, decision-making, adaptation degree, and IT performance are often inferior to the anticipation. The assimilation of technology can be defined by the extent to which the use of Information technology spreads across organizational processes and becomes routinized in activities. Capabilities of information technology play crucial role in an ever-changing environment and are considered as one of the most important sources for enterprises while enterprises should acquire some effective capabilities so that they can effectively deploy and utilize information technology. But companies need to increase their Absorbency of IT to accept it for effective use of IT, since the acquisition and use of information technology is simply not feasible and any information technology does not create value. The purpose of this investigation is to represent a model to measure absorbency of information technology in small and medium-sized enterprises. To do so, dimensions of the "absorbency of information technology" was determined through exploratory factor analysis in a survey research and confirmatory factor analysis was used to confirm model validity. Findings show that three dimensions are related to absorbency of information technology including the capability for innovative technology, Inside-Out IT capability and IT management capability, among which the capability for innovative technology has the highest correlation with the concept of absorbency of information technology.

Keywords: Absorbency of Information Technology; Capability for Innovative Technology; Small and Medium-Sized Enterprises; Inside-Out IT Capability; IT Management Capability.

1. Introduction

Nowadays many of small and medium sized enterprises (SMEs) are faced with difficulties in market situation. For example: increasing globalization, increasing competition, improvements of information and communication technology (ICT) and changes in organizational structure [1-2].Therefore, in order to keep the competition in a messy market, required resources for the enterprise should constantly be evolved and improved [3]. Information technology (IT) has been recently found as a key resource input to firms' innovation activity [4] and due to its potential and actual effects as well as saving, processing and producing knowledge and information in SMEs, is an attractive realm for investment [5]. In a global conditions for business and due to improvements in IT, SMEs are forced to use novel technologies to preserve their competitive ability. In recent years, many firms have accepted technologies like electronic business, social networks and virtual society [6] and believe that in order to survive in globalization era, it is necessary to absorb these technologies [7]. In addition, by the support of IT enterprises can obtain some abilities to create superior value to fulfil customers' demands [8] and to improve their financial operation [9]. But some researchers, with regard to the strategic role of IT in an enterprise, have stated that IT is not suitable for any SMEs [10-11]. information technologies in the organization may cause problems related to their management and use, problems that may be not only technological but also managerial in nature [12-13] and it may cause some management problem for them [14]. [15], in their study concluded that to absorb IT, it is required to create extensive adaption between technology and enterprise and a considerable number of enterprises can't afford such adaption and therefore, they lose most of the benefits that re resulted by IT. Although there are some studies suggested to absorb IT [16-15], still it is not clear which method and structure is suitable to facilitate this absorption [17]. [18] emphasis that to create value, it is necessary to understand different aspects of absorption of IT. Therefore, with respect to the properties of SMEs

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compared to other organizations, these enterprises are suitable ground for studying about IT assimilation [19]. This article is trying to suggest the concept of "absorbency of IT" based on the concept on IT assimilation. To do so, after considering previous researches about IT, this article introduces absorbency of IT and then, represent a model to measure it. In order to represent the model, first, based on the concept of absorbency of IT, this question should be answered that what are the dimensions of absorbency of IT? What are the elements of each dimension?

2. Research Background

In this section and in the form of theoretical background, first the important concepts of the study like absorption and Capability of IT are discussed. Then, in the part about experimental background, some performed studies will be introduced and at the last part, the model of this investigation will be represented.

2.1 Theoretical Background

IT assimilation is about its applicability depth and vastness in the Firm procedure [20] and organization activities [21]. The assimilation of IT can be defined under a multidimensional perspective that involves the following: [22]

- Acceptance or rejection by the user;
- The institutionalization and diffusion of the system in the company's business processes; and
- Support for operational control and management and monitoring of business strategies.

[23-24] stated that IT adoption and assimilation in an organization are determined by numerous factors that can be placed into one of three categories of TOE (Technology, Organization and Environment) proposed by [25]. The TOE framework as originally presented and later adapted in studies of IT adoption provides a convenient analytical framework that can be used to study the adoption and assimilation of different types of IT innovation [26]. Technological factors describe the characteristics of the technological environment, which can influence the spread of systems in an organization. These features include various dimensions of technology due to the advantage to the quality of the system's information, which increases the spread of IT in the organization. Organizational factors refer to the scope, resources and size of the organization, and the environment dimension refers to the context in which the company develops its industry, competitors and government relations [25]. [26] describe these factors as suitable framework to assimilation IT in enterprises.

On the other side, the capability of IT is the capacity to control relevant costs of it, delivering systems when it's necessary and effecting on business goals through implementing IT [27]. This capability is considered from different dimensions: how it is related to its design, process change, power relations and cooperation [28], improvements in IT capabilities leads to achieve a forward looking in enterprises, improvements in production programming, inventory and distribution management [29]. According to a perspective that uses resource-based view, valuable, rare, inimitable and irreplaceable resources, provide competitive advantage for SMEs, therefore IT should be considered as an organizational capability that leads to competitive advantage through guiding enterprise to perform superior performance [30] and since organizational capabilities or merits re-formed through integration of base resources [31] it can be said that IT capability is a combined factor source. Combined resources are measurable through their components and these lower level components can be either tangible or intangible [32]. Therefore, IT capability can have different dimensions equivalent to its distinct information- based resources. However, to develop the total dimensions of IT capability, one should focus on information-based technology resources that lead to this capability. For example, [27] said that IT capability depends on three different kinds of assets including IT human resource, IT technical resources and IT communication resources and it is a strategic capability to manage these three assets to apply IT in order to meet the goals. [33] adjusted this classification and divided the information-based technology resources of the enterprise into three groups of IT infrastructure, IT human resource an IT intangible resources that are more attractive in IT literature. [34] divided IT capabilities into three groups: outside-in, inside-out, and spanning Outside-in IT capabilities are outward-facing. For example, a virtual community is an outside-in IT capability that allows firms to develop external relationships and collect knowledge from the external environment. Inside-out IT capabilities are inward-focused. For instance, technology platforms and IT skills are inside-out IT capabilities that enhance a firm's ability to seize market opportunities. Finally, spanning IT capabilities integrate a firm's outside-in and inside-out capabilities. For example, knowledge management systems enable storing, archiving, retrieving, and sharing of current knowledge to gain a better understanding of how new external knowledge relates to what organizational members already know. [35] considered value, dynamic and competitive capabilities as three different kinds of IT capabilities. About competitive capability these researchers said that IT business experience and communicative resources of IT can improve competitive advantage of the enterprises. In addition, IT capabilities normally effect on enterprise operation and provide higher levels of business for it [36]. Organizational performance is one of the most important constructions in meeting organizational goals [37] and the most important measure in evaluating commercial enterprises success.

Therefore, enterprises to create value through using IT, should reach to a specific penetration level. [38] believe that penetration of technology introduction into the business and education procedures, can lead to innovative application of IT. In order to make IT advantages and

benefits available to enterprises, they should be at the suitable level of absorbency. Lack or deficiency of absorbency in an enterprise, directly influences on steps in evolutionary path of IT assimilation and impede the progress of IT assimilation, even causing IT project to cease and leading to "assimilation gap". So, while implementing complicated informational systems, it is necessary for managers to pay attention to IT absorbency in order to successfully implement the system and guarantee its ongoing application [39].

2.2 Experimental Background

In considering enterprises abilities and capabilities to absorb and use IT, there are several studies in the literature. Primary reviews show that there are differences between IT absorbency, its application and identifying its fundamental capabilities. For example there is difference between tools to reduce the cost [40], communication and customers and suppliers relationship tools [33]. The second wave of studies in technology investigations is about the effect of IT on the individuals' potential power and its effect inside the organization that has been performed by [41] and is mostly concerned about some properties like resource allocation, network focus, expertise and discretion. Next wave of studies were in 1990s and studied about the effect of IT on business redesigning process in which totally 9 basic capability were identified that lead to strong relationship between IT and business redesigning process [42].

On the other hand, [43] found that IT capabilities has positive and direct effect on organizational performance and this lead to important consequences for managers in evaluating investment on IT. [44] stated that IT enables organizations to continuously and gradually, change the knowledge achieved through cumulative experience into a practical knowledge, tangible efficiency and improvement of quality.

[45] suggested that IT capabilities are dependent on external environment properties which the enterprise in competing. [46] discussed about the role of technical capabilities in adjusting competitive strategies relation in enterprises operation. His results showed that technical capabilities have positive effect on organizational performance. [47] classified the IT capabilities into two groups of technical skills (education, experience and vision) and management capability (using technical skills to predict the technology). [48] discussed about the effect of IT based capabilities on enterprises operation with respect to the processes and operations that are supported cloud computations. Their result showed that communicational capability of IT, compared to technical and managerial abilities, has the most influential factor in facilitating success.

Findings of [49] showed that ERP implementation strategies don't directly effect on organizational performance, rather IT hybrid capabilities play as a tool to facilitate the relation between efforts to implement ERP system and the results of competitive performances in enterprises. In this article, it has been tried to use a hybrid perspective about the dimensions of IT capabilities.

Reviewing literature shows that researchers discussed about IT capabilities from different perspectives, but there is no consensus about element for IT capability and how to measure it. Since there is no model or scale to measure the IT capability, it is necessary to define a new concept to evaluate IT assimilation in SMEs, which will be discussed as follow.

2.3 Conceptual Model

In order to review and evaluate enterprises ability in different fields, investigators have introduced different capabilities in literature all of which are gathered under the title of organizational capability. IT can be one of these organizational capabilities [30] so in this study, hybrid perspective about dimensions of IT capability is used. This study, through reviewing literature and focusing on basic resources, has integrated the theory of resource advantage and has represented a wider perspective about IT capability called "IT absorbency".

IT absorbency is defined as "organization capability in a way that it can apply its IT resources in an effective way and in relation to other resources so that it can manage information inside the organization, improve the performance and create competitive advantage". According to this definition, literature review and basics of theory to measure the IT absorbency it is necessary to consider three capabilities. In other words, an organization has a high level of IT absorbency that has a proper performance in three dimensions of IT resources, management and improving the performance and also in turn uses basic concepts of Inside-Out IT Capability [34], IT management Capability [33-47] and Technological Innovation Capability [50-51].

Inside-Out IT Capability

Inside-out IT capability are inward-focused. For instance, technology platforms and IT skills are inside-out IT capability that enhance a firm's ability to seize market opportunities Integrated information systems provide immediate access to standardized data across organizational units, which in turn allow the organization to more readily apply new knowledge to create products and services [52]. At inter-organizational level, Inside-out IT capabilities, like electronic commerce interactions will increase company's ability to recognize the valuable knowledge and exchange it with other co-operators or other companies. This leads to another form of side relation that supports knowledge stream in organizational limits [53]. Predetermined formats, will enforce applying and exchanging information and helps the enterprise to recognize the valuable knowledge. Enterprises that use shared decision-making mechanisms, contribute in richer knowledge about customers, technologies and markets through participating in collective decision making about effective factors in their processes of electronic exchanges. In addition, combining exchanged information with

shared decision-making processes through standard electronic commerce, leads to a deeper understanding about needs of each side and this will in turn increase their environmental self-awareness [54]. Therefore, Inside-out IT capabilities, reinforces enterprise' ability in recognizing and developing IT.

IT Management Capability

[55] have defined IT management capability as "a distinct set of human, motivational and behavioural skills that have different potentials to achieve special activities which are effective in business performance". They have argued that an IT capability is a capability to facilitate supporting and utilizing IT in order to improve business performance. SMEs keep their close relationship with their employees and have informal relations between manager and employees, informal structure and also informal processes. IT management capability performs facilitating mechanisms for entrance of valuable IT in to the enterprise so that it can obtain ore value. Human resources of IT represent intangible assets that are an important introduction for IT capabilities in enterprises [56]. Generally, human resource in IT represent education, experience and vision [57] that develop technical and managerial skills and capabilities. IT management capability is the extent to which managers should possess technical skills and business intelligence to predict emerging technology and its effective lever in balancing commercial processes with organizational goals [48]. The effective factor for successfully implementing new system in the enterprise is the ability of IT managers in coordinating multilateral activities that are relevant to implementation [58]. Studies have shown that managerial abilities have positive effect on competitive advantage or enterprise performance. In addition resource-based theories believe that enterprise capabilities represent resources that may be used for increasing efficiency and competitive advantage [48]. Therefore, managers should provide a situation under which employees are able to identify and exchange new information technologies. To create such a situation, there is no specific and standard instruction. So, managers can actively create an atmosphere in which employees have the motive to exchange IT and this exchange is easily done through informal relationships. According to [59], informal relationships are good source for small enterprises, since knowledge and IT will be achieved

Technological Innovation Capability

Innovation, as an intangible asset, is the foundation for any organization's survival [60] and those enterprises that use it successfully, can create competitive advantage in the market [61]. Responding to competitive environment, organization and countering possible internal and external threats are some factors contribute to applying innovation [62]. Therefore, innovation capability is an organization's asset and obtaining IT dependent on enterprises innovation capability [63]. Results from a study by [64] showed that the speed of innovation has positive and significant effect on performance. Faster innovation leads to better performance. The speed of innovation makes it possible to react to the environment faster and represent a new product in a minimum possible time and cost and finally will lead to improvement in organization performance [65]. The concept of technological innovation capability first was raised at the beginning of 1980. This concept discusses about level of technology changes in order to achieve technological capability [66]. [67] define technological innovation as "a procedure by which the enterprise is dominant in designing and producing new product, regardless of whether or not these products are new to their local and foreign competitors". Technological innovation, is the process of developing new products or technologies, has important effect on enterprise operation [68]. [50] defined the technological innovation capability as "organization's required knowledge and skill to choose, install and maintain, adaption, improving and developing technologies inside the organization". Furthermore, technological innovation capability is defined as a set of tools, skills, knowledge, talent and intentions of the enterprise that lead to the ability to produce, understand, change and create procedures and products [51]. [69-70] considered the technological innovation capability as an important factor in company's development and emphasized on the importance of evaluating it. [71] Believe that developing technological innovation capabilities can be useful for the enterprise and leads to its competitiveness. [72] discussed about the effects of using innovations of technology in improving competitiveness and assuring companies stability. In addition, [73] argued that technological innovation capability is measurable through dimensions like technology infrastructure, production, knowledge, experiences and organization.

3. Methodology

In order to know different aspects of IT absorbency and representing a model to measure this capability in SMEs, first according to the literature review and previous studies, effective indices in IT absorbency in SMEs were extracted. Then, through filtering these indices by the experts, a questionnaire was extracted through forming special panels and by using experts' opinions that involved 25 questions among which 13 questions were dedicated to measuring technological innovation capability, 6 questions dedicated to measuring internal capability of IT and 6 questions dedicated to evaluate IT management capability. Population of this investigation involved all employees with bachelor or higher education, managers of production, sale, marketing and service units, ad senior managers of production SMEs in Iran. With respect to the identified population, the required sample number to test the model based on Cochran Formula was 650 people. After distributing 680 questionnaire, finally 587 questionnaires were received (86 percent) and analysed. Since the population was specific and there were some lists of individuals and enterprises, random sampling method was performed.

Among 587 respondents, 321 people had bachelor, 213 people had master and 53 people had Ph.D.

With respect to the purpose, this is an applied investigation and with respect to data gathering method, is descriptive with correlation, in a way that by reviewing relevant theories, first dimensions of the investigation are identified from theoretical perspective. Then, these identified dimensions are tested through a survey (production SMEs). Tool for data gathering and measuring variables of the study is a questionnaire which is prepared in the form of Likert scale. To consider the correctness of validity, before distributing the designed questionnaire, that was judged by some experts and necessary corrections were applied to it. Furthermore, divergent validity (exploratory factor analysis) and convergent validity (first order confirmatory factor analysis) were used to confirm the validity of the questions in the questionnaire. After first order confirmatory factor analysis, three questions (question B1 in Inside-Out IT capability aspect, questions C5 and C6 in IT management capability aspect) were omitted because of little correlation. In exploratory factor analysis KMO value of questions was 92% that represents sampling adequacy. In addition, since Bartlett test is significant in error level of 0.05% (sig equals to zero and less than 0.05), the factor analysis was suitable to identify and discover the structure. Furthermore, to calculate questionnaire reliability, Cronbach's Alpha was used with the help of SPSS software and its result was calculated to 0.90 that shows high reliability of the questionnaire. Its dimensions' reliability were 0.71, 0.75 and 0.83 respectively. Designed questions are represented in three suggestive dimensions in table1.

Table 1. Proposed benchmark for measuring absorbency of information technology

	Technological Innovation Capability
A1	By utilizing information technology in our company, products and services are offered with better quality.
A2	Since employment of information technology in our company the customers' demands are met with high speed and quality.
A3	Applying information technology in our company has caused human errors and release of defective products to decrease.
A4	Using information technology in our company has enhanced instant access to standard information for different units of the company
A5	Utilizing information technology in our company has increased new products and services.
A6	Utilizing information technology in our company has increased the use of appropriate software and hardware equipment in administrative procedure.
A7	Exploitation of information technology in our company has accelerated the purchase and service rendering process.
A8	Utilizing information technology in our company has caused newer and better procedures for meeting the market's demands to develop.
A9	Information technology have promoted the improvement of our personnel (in receiving information appropriately making decision independently and better).
A10	The use of software and hardware tools in coordination between different sections of company has increased.
A11	Employment of information technology has encouraged the personnel to exchange and update the information on knowledge base.
A12	By the arrival of information technology at our company, work procedures have been simplified.
A13	Exploiting the information technology has facilitated the introduction of products and services to the customers.
	Inside-Out IT Capability
B2	Information technology development in our company has caused the price of our products and services to be suitable and competitive.
B3	Exploitation of information technology has caused development of e-commerce in our company.
B4	Information technology has caused our products and services to go beyond frontiers.
B5	Since employment of information technology, the customers use our products and services more than that of rival companies.
B6	Using e-commerce has accelerated achieving the company's goals.
	IT management Capability
C1	In our company, the information technology applied by the company has resulted in delegating some authority to the staff.
C2	By accepting information technology, some positions have been integrated or removed.
C3	Information technology has given our manager the chance to manage in a simpler way by quickly processing the information.
C4	Information technology has extended the range of marketing for our company.
	Three deleted questions after factor analysis
B1	In our company, using information technology has reduce production or service rendering expenditure.
C5	In our company, informal communication between the manager, personnel and customers has been enhanced owing to information technology.
C6	Our company uses social networks, SMS, email and remote conference to communicate with people.

Findings

In this investigation, in order to identify latent variables, exploratory factor analysis (EFA) was used. EFA should be used when the researcher has no a priori hypothesis about factors or patterns of measured variables or for Reclassification of component. 25 questions are designed to measure IT absorbency among which 3 questions were omitted due to their unsuitable factor structure. Then, with the help of exploratory factor analysis and first order Varimax rotation, three factors were identified as it is represented in table 2. According to theoretical grounds of the investigation and experts' opinions, the first factor (A) is called technological innovation capability, second factor (B) is called Inside-Out IT capability and third factor (C) is called IT management capability. Furthermore, questions' validity was approved.

Table 2. Rotated Component Matrix

	Component		
	Technological Innovation Capability	Inside-Out IT Capability	IT Management Capability
A1	**.722**	.288	-.014
A2	**.692**	.307	.059
A3	**.684**	.194	.010
A4	**.717**	.139	.151
A5	**.643**	.248	.121
A6	**.687**	.105	.174
A7	**.610**	.212	.133
A8	**.624**	.240	.120
A9	**.639**	.117	.286
A10	**.623**	.190	.168
A11	**.580**	.318	.084
A12	**.565**	.017	.356
A13	**.420**	.307	.409
B2	.222	**.801**	.043
B3	.236	**.774**	.099
B4	.147	**.757**	.135
B5	.218	**.691**	.158
B6	.330	**.657**	.131
C1	.101	.063	**.752**
C2	.007	.065	**.720**
C3	.378	.217	**.593**
C4	.302	.397	**.478**

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative%
technological innovation capability	8.378	38.083	38.083
Inside-Out IT capability	1.749	7.951	46.035
IT management capability	1.498	6.811	52.845

First and second order confirmatory analysis are used in this study. In the first order confirmatory analysis, we reached to the latent variable through indices and this latent variable is used to validate questions in the questionnaire and second order confirmatory analysis is also used to consider correlation between first order latent variables and the variable for IT absorbency.

As it is shown in table 2, model practice is calculated. If the reported values of the indices is in a desired level, the structural model will be confirmed. If the ration of Chi-squared to the degree of freedom (df) is less than 3, RMSEA is less than 0.08 and NFI,RFI and IFI higher are than 0.9 and Parsimonious indices (PCFI,PNFI) are higher than 0.5, it can be concluded that this model has a suitable practice [74]. Findings from table 3 show that all practice indices are at desired level and hence, structural model will be confirmed.

Table 3. Fit indices for structural equation modeling

indices	favourable	achieved score
X2/df	Between 1 and 5	4.60
GFI	0.9 and higher	0.93
NFI	0.9 and higher	0.93
RFI	0.9 and higher	0.92
IFI	0.9 and higher	0.94
CFI	0.9 and higher	0.94
PNFI	0.5 and higher	0.83
PCFI	0.5 and higher	0.89
RMSEA	Smaller than 0.08	0.078

After confirming fitness of pattern in a logical form, significance of model components and relations between variables are evaluated. In figures 1 and 2 estimation of Lisrel parameters in a tested pattern are represented. These parameters all show the simultaneous effectiveness of each observer and latent variable in a general framework. By standard coefficient we mean values of binary correlations (between two variables) and it is used to compare the effects of model components and is totally used to confirm or reject the hypotheses of the study. How much the significance value is higher than 1/96 or lower than -1/96, represents that the independent variable has strong effect on dependent variable. Is it is clear in figure 3, all three main hypotheses of the investigation are significant and have high standard coefficient. In the fitted model there is the effect of each dimension on absorbency. More coefficients in the dimensions means they have more effect on absorbency. Among considered dimensions in this study, technological innovation capability (A) with the impact coefficient of 0.89 has the highest effect on IT absorbency. Next IT management capability with the impact coefficient of 0.80 and then Inside-Out IT Capability with the impact coefficient of 0.75 have the highest effects.

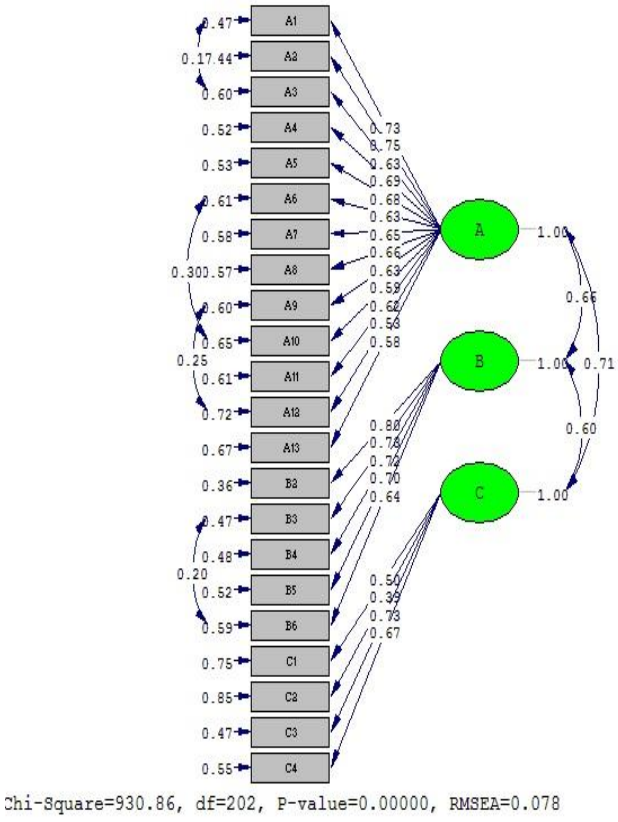

Fig. 1. First order factor analysis in standard mode

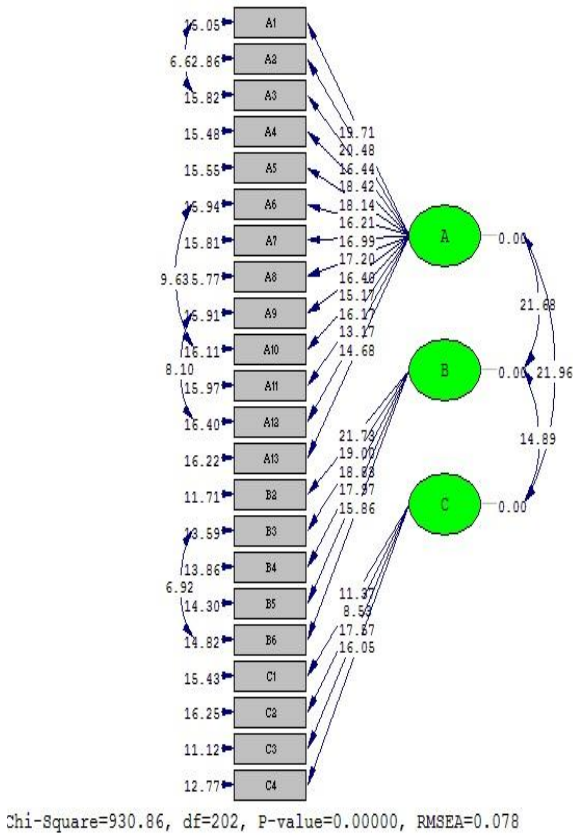

Fig. 2. First order factor analysis in standard mode coefficient

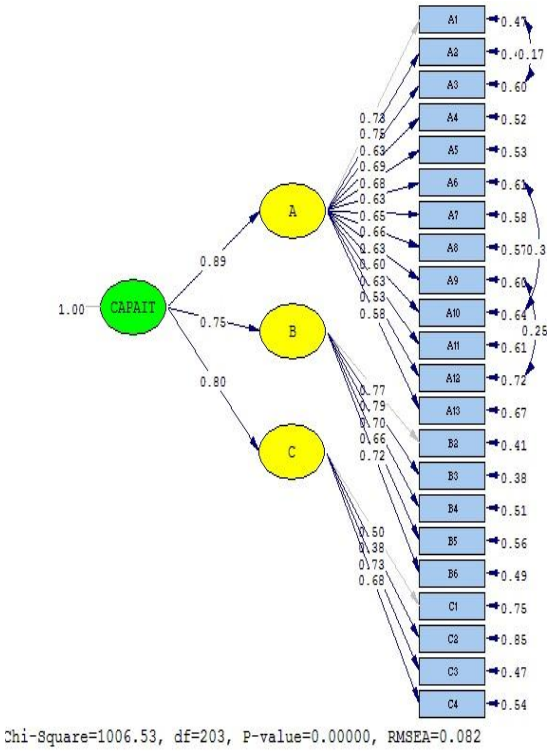

Fig. 3. Second order factor analysis in standard mode

4. Conclusion and Suggestions

In order to investment in development and IT assimilation of IT and its effectiveness, some capabilities should be considered in SMEs. IT, to be successful of unsuccessful in enterprises, needs to identify some capabilities and determine their significance. IT is the most important way to improve the performance in long term and just an organization can achieve to superiority in short term that is able to utilizing IT absorbencies in all organizational levels. The purpose of this study is to represent a model to measure IT absorbency in SMEs upon which managers can evaluate their own enterprise capability in absorbing IT. Findings show that three suggested dimensions have correlation with the concept of IT absorbency and factor analysis, confirms components' classification in three dimensions. In addition, findings show that among suggested dimensions, technological innovation capability has the highest correlation with IT absorbency that emphasizes on continuous innovation in products and procedures so that the enterprise can respond to the environmental changes including customers' increasing demands. Technological innovation is crucial for economic development and ignoring it has guided several enterprises into the destruction. This concept helps managers to provide a ground for their economic growth by choosing the most suitable technology as well as maximum use of available technology. These findings confirm studies of [69-70-72-62] but in the first dimension, that is technological innovation capability, question A2 has the most correlation and confirms that through applying IT in the enterprise, customers' demands are met with high speed and quality. Companies should try their best to serve services to their customers [75-76-8]. Applying IT can make the customers satisfied and companies can exchange their knowledge with their customers and this in turn will lead to producing new products in accordance to market demand and rings financial profitability and improves the enterprise operation (Similar to results: [77-78-79]). In the second dimension, that is Inside-Out IT Capability, question B2 has the highest correlation with IT absorbency. Developing a technology for internal information leads to supplying products or services with a suitable and competitive price. Those SMEs that actively are concerned about market changes and developing technology and respond to the market demand with new products and services, increase their competitive success. SMEs investment in IT is necessary for survival and competiveness, especially for international capacities and innovation (Similar to results: [80-81-82]). Furthermore the most relevant correlation is in the third dimension, which is IT management capability that is relevant to C3 questions. These findings show that IT has caused the management to manage the enterprise in a simpler way through fast processing of information. IT based systems provide more flexibility for companies to omit time and space limitations (Similar to results: [83-84]). Hence, following suggestions are useful to improve IT absorbency SMEs.

1. Identification and absorption of IT in SMEs should be more efficient and its being fitted with available capabilities should be considered.
2. SMEs don't have a correct definition of IT absorbency. So it can be said that they haven't considered all tools and factors of each capability and even they apply them, they can't establish necessary and sufficient integration between them, therefore, it is suggested that after identifying capabilities, their dimensions' integration must be reviewed.
3. Some capabilities must be considered in SMEs so that they provide a ground for identification, deliverance and application and distribution of IT all over the enterprise.
4. Since time passes by and because of applying IT and its rapid change, it is suggested that the conceptual model of the study will be retested in a three years period, and its results will be compared to the results of this study.
5. This investigation has been reviewed in SMEs while the presented model could be tested in big or private industrial companies.
6. Results from this investigation, doubtlessly are derived from experts opinions and time and space conditions in this territory are considered. So, it is suggested that identified dimensions are tested in other places and their importance is measured.
7. Considering how to apply the right approach in order to achieve all dimensions of IT absorbency in the companies can be another issue for future investigations.
8. It is suggested that other models of IT absorbency are tested for SMEs.

This study faced some limitations. To generalize the results of this study for other small, medium or large enterprises, should be done prudently and also inherent limitation of the questionnaire in data gathering should be noticed.

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A Global-Local Noise Removal Approach to Remove High Density Impulse Noise

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Received: 12/Jan/2017 Revised: 08/Nov/2017 Accepted: 11/Dec/2017

Abstract

Impulse noise removal from images is one of the most important concerns in digital image processing. Noise must be removed in a way that the main and important information of image is kept. Traditionally, the median filter has been the best way to deal with impulse noise; however, the image quality obtained in high noise density is not desirable. The aim of this paper is to propose an algorithm in order to improve the performance of adaptive median filter to remove high density impulse noise from digital images. The proposed method consists of two main stages of noise detection and noise removal. In the first stage, noise detection includes two global and local phases and in the second stage, noise removal is also done based on a two-phase algorithm. Global noise detection is done by a pixel classification approach in each block of the image and local noise detection is performed by automatically determining two threshold values in each block. In the noise removal stage only noise pixels detected from the first stage of the algorithm are processed by estimating noise density and applying adaptive median filter on noise-free pixels in the neighborhood. Comparing experimental results obtained on standard images with other proposed methods proves the success of the proposed algorithm.

Keywords: Impulse Noise; Noise Detection; Noise Removal; Adaptive Median Filter.

1. Introduction

Digital images are normally corrupted by many types of noise, including impulse noise. Impulse noise, even with a low noise percentage, can change the appearance of the image significantly. This is because, the impulse noise, normally has a very high contrast to its surroundings. Malfunctioning pixels in camera sensors, faulty memory locations in hardware, or transmission of the image in a noisy channel, are some of the common causes for impulse noise in digital images. The amplitude of the corruption is relatively very large compared with the strength of the original signal. As a consequence, when the signal is quantized into L intensity levels, the corrupted pixels are generally digitized into either two extreme values, which are the minimum or maximum values in the dynamic range (i.e. 0 or L-1). For this reason, impulse noise normally appears as white or black dots in the image, thus also referred as salt-and-pepper noise [1]. Median filtering, because of its nonlinear behavior, is suitable to remove the impulse noise in image. This is because of their simplicity and capability to preserve edges. The filter mechanism is to replace each pixel value with the median of neighboring pixel values in the window. Standard median filtering is a good choice to achieve reasonable results, but, the problem arises when the ratio of the noise is higher than 50%, in which there is a good chance that median is a corrupted pixel rather than a clean one [2]. Many variations of median filter have been proposed. In the adaptive median filter, window size will change according to the noise level [3]. At higher noise densities a larger window size is used and at lower noise densities a smaller window size is used. This method is very time-consuming due to increasing the window size and has poor results in high density noises because it replaces a pixel with another pixel which is in a far distance from it and so less correlation with it [4]. Replacing a far pixel with a noisy one mainly results in edge loss and blurring [2]. Weighted median (WM) filter selectively give some weights to pixels in the filtering window usually with the central pixel contributing the most [5]. Although the detail-preserving abilities of WM filters are better than median filters, their noise removing abilities are not as effective [6]. Topological median filter (TMF) operates based on a computed connectivity map and therefore is relatively unaffected by disconnected features in the neighborhood of the center pixel [7]. TMF and WM result in better preserving of edges and details, however, the resulting image quality is not desirable since uncorrupted or noise free pixels are also processed and it causes loss of great details from image, such as thin lines. Most of the past median filters were designed on the basis of detection of noise pixels before image filtering, also known as decision

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based or switching algorithms. Impulse detector of [6] is based on absolute difference of pixel value and median or weighted median value in a neighborhood of pixel. A progressive switching median filter, where impulse detector is applied progressively in iterative manner, has been proposed in [8]. Impulse noise detection technique of [9] is based on the minimum absolute value of four convolutions obtained using one-dimensional Laplacian operators. In [10] noise detection is performed at two stages: noise candidates are first selected using the homogeneity level, and then a refining process follows to eliminate false detections. The algorithm of [11] is based on a fuzzy impulse detection technique. In [12] a global-local noise detector is proposed and removing noise is performed based on adaptive median filtering. In [1] based on only the intensity values, the pixels are roughly divided into two classes, which are "noise-free pixel" and "noise pixel". Then, adaptively changes the size of the median filter based on the number of the "noise-free pixels" in the neighborhood. For the filtering, only "noise-free pixels" are considered for the finding of the median value. In [13] in the first stage, the positions of noise pixels are detected by thresholding the absolute difference between the noisy image and its sparse representation. In the next stage, the pixels that are detected as noisy ones are replaced using image in-painting through sparse representation. In [14] a new impulse detection algorithm based on combination of Luo-statistic and k-means clustering has been presented. In [15] the difference between the central pixel and its neighbors aligned in four directions in a local window is used to detect noise. Then the noisy pixel is replaced by a histogram weighted mean filtering value. In [16] the concept of two threshold values for detection of impulse noise is introduced. Proposed method in [17] employs an artificial neural network to decide whether a pixel is corrupted or not. In [19] the proposed technique consists of two stages: noisy pixel identification and restoration. In the first stage absolute directional difference of the neighborhood pixels is used to identify the noise pixels. In the second stage an edge preserving contextual model based on a Gaussian kernel is proposed to restore these pixels. In [20] a combination of adaptive vector median filter (VMF) and weighted mean filter is proposed for removal of high-density impulse noise from color images. In the proposed filtering scheme, the noisy and non-noisy pixels are classified based on the non-causal linear prediction error. For a noisy pixel, the adaptive VMF is processed over the pixel. Whereas, a non-noisy pixel is substituted with the weighted mean of the good pixels of the processing window.

In this paper, it has been attempted to achieve more desirable results by presenting an algorithm to detect and remove noise. The proposed method combines the advantages of the methods in [1] and [12] in order to achieve better results in terms of visual quality.

Rest of the paper is organized as follows. In section 2 the proposed algorithm including noise detection and noise removal stages is discussed. Section 3 reports the experimental results of proposed algorithm, and the paper ends with concluding remarks in Section 4.

2. Proposed algorithm

Noise detection and noise removal are the main steps to eliminate noise from natural digital images which in this paper each one contains multi implementation levels. The figure below shows a block diagram of the proposed algorithm.

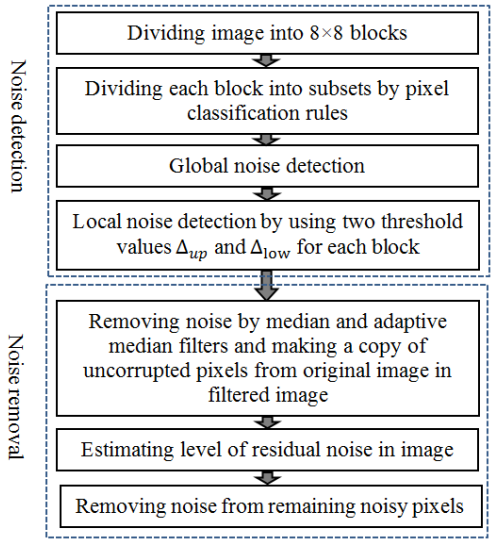

Fig.1. Block diagram of the proposed algorithm

We will explain more about different parts of the block diagram in the rest of the paper.

2.1 Global - Local Noise Detection

Noise detection process is a combination of global and local noise detectors [12]. For this process, the noisy image is divided into M×M blocks which are neighbors together but not overlapping each other, while uncorrupted pixels in each block should be homogeneous. According to [18] if the block size is chosen 8×8, uncorrupted pixels in each block can be assumed homogeneous. Also, it is assumed that the maximum and minimum values in the dynamic range represent the impulse noise.

2.1.1 Pixel Classification in Each Block

After that the image was divided into 8×8 blocks, assume that $Q_{8\times8} = \{p_{1,1}, p_{1,2}, \dots, p_{1,8}, \dots, p_{8,1}, \dots, p_{8,8}\}$ shows a set of all pixels in a 8×8 block. $p_{i,j}$ represents the pixel in row i and column j of this block. $q_1, q_2, \dots, q_{64}$ are the pixel intensity values of the $Q_{8\times8}$ set in ascending order. $q_1, \dots q_i, q_{64}$ will be classified as follow [12]:

If $\varphi_1, \dots, \varphi_l$ are subsets of $Q_{8\times8}$ and include $q_1, \dots q_i, q_{i+1}$ where: $\varphi_l = \{q_j, \dots, q_i, q_{i+1}\}$ and $1 \le l, 1 \le j \le i+1$. and if φ_{l+1} is an empty set and $q_{i+2}, q_{i+3}, \dots q_{64}$ are not classified, three rules of pixel classification for classification of q_{i+2} are as follow:

1. If $\frac{q_{i+2}-q_{i+1}}{q_{i+3}-q_{i+2}} \le 2$, q_{i+2} belongs to φ_l, otherwise q_{i+2} is added to φ_{l+1} subset, note that if $q_{i+2} - q_{i+1} = q_{i+3} - q_{i+2} = 0$, let $\frac{q_{i+2} - q_{i+1}}{q_{i+3} - q_{i+2}} = 1$.

2. If $\frac{q_{i+2}-q_{i+1}}{q_{i+3}-q_{i+2}}<\frac{1}{2}$, $q_{i+3} \in \varphi_{l+1}$.
3. If $\varphi_{l+1}=\{q_{i+2}\}$ or $\{q_{i+3}\}$, a new empty subset φ_{l+2} is initialized and pixel classification for φ_l is finished.

Based on these three rules, $q_1, \dots q_{64}$ will be classified. Finally, $Q_{8\times8}$ set is divided into L subsets, so that $Q_{8\times8}=\cup_{l=1}^{L}\varphi_l$.

Since with the selection of 8×8 block size, free-noise or uncorrupted pixels can be assumed homogeneous in all block, the difference between these pixels are too small and noisy pixel values are significantly different from noise-free pixel values. So the noise-free and noise pixels are two obviously different types of pixels. Thus, in general, each subset of $Q_{8\times8}$ could only include one type of pixels: noise-free or noisy ones.

2.1.2 Global Noise Detection

Before the noise pixels are identified, we give a definition of the degree of similarity between two subsets. Let $\tilde{Q}8\times8$ and $\bar{Q}8\times8$ be any two 8×8 blocks of a noisy image. Let $\gamma(\tilde{\varphi}l, \bar{\varphi}m)$ denote the degree of similarity, where $\tilde{\varphi}l$ and $\bar{\varphi}m$ are any two classified subsets of $\tilde{Q}_{8\times8}$ and $\bar{Q}$ 8×8, respectively. Let $\tilde{\varphi}_l=\{\tilde{q}_{l,1}, \tilde{q}_{l,2}, \dots, \tilde{q}_{l,k}\}$ and $\bar{\varphi}_l=\{\bar{q}_{m,1}, \bar{q}_{m,2}, \dots, \bar{q}_{m,n}\}$, where $\tilde{q}_{l,1} \le \tilde{q}_{l,2} \le \cdots \le \tilde{q}_{l,k}$ and $\bar{q}_{m,1} \le \bar{q}_{m,2} \le \cdots \le \bar{q}_{m,n}$. For $\gamma(\tilde{\varphi}l, \bar{\varphi}m)$, two cases are listed as follows:

1. If $\tilde{q}_{l,1} \le \bar{q}_{m,1} \le \bar{q}_{m,n} \le \tilde{q}_{l,k}$, let

$$\lambda_{h_1,h_2}=\sqrt{\frac{1}{n_\lambda}\sum_{i=1}^{n_\lambda}\left(\bar{q}_{m,h_1+i}-\tilde{q}_{l,h_2+i}\right)^2} \quad \text{and}$$

$$\mu_{h_1,h_2}=\min\left(\left|\frac{\bar{q}_{m,h_1+n_\lambda}-\bar{q}_{m,h_1+1}}{2(n_\lambda-1)}\right|, \left|\frac{\tilde{q}_{1,h_2+n_\lambda}-\tilde{q}_{l,h_2+1}}{2(n_\lambda-1)}\right|\right),$$

where:
$n_\lambda=\min(n,k)$, $0 \le h_1 \le n-n_\lambda$, and $0 \le h_2 \le k-n_\lambda$. Then

$\gamma(\tilde{\varphi}l,\bar{\varphi}m)=1-\min_{h1,h2}\left(\frac{\lambda_{h_1,h_2}}{\mu_{h_1,h_2}}\right)$,

if $\lambda_{h_1,h_2}=0$ and $\mu_{h_1,h_2}=0$, let $\left(\frac{\lambda_{h_1,h_2}}{\mu_{h_1,h_2}}\right)=0$.

2. If $\tilde{q}_{l,1} \le \bar{q}_{m,1} \le \tilde{q}_{l,k} \le \bar{q}_{m,n}$, suppose:

$\hat{\tilde{\varphi}}_l=\{\tilde{q}_{l,j-1}, \tilde{q}_{l,j}, \dots, \tilde{q}_{l,k} \in \tilde{\varphi}_l | \tilde{q}_{l,j-1} \le \bar{q}_{m,1} \le \tilde{q}_{l,j}\}$

And $\hat{\bar{\varphi}}_m=\{\bar{q}_{m,i} \in \bar{\varphi} | \bar{q}_{m,i} \le \tilde{q}_{l,k}\}$, where:
$1 \le i \le n$ and $1 \le j \le k$.

Let $\eta(\varphi)$ denote the number of elements in set φ.

If $\max\left(\frac{\eta(\hat{\tilde{\varphi}}_l)}{\eta(\tilde{\varphi}l)}, \frac{\eta(\hat{\bar{\varphi}}_m)}{\eta(\bar{\varphi}m)}\right)<\frac{2}{3}$, $\gamma(\tilde{\varphi}l, \bar{\varphi}m)=0$,

Otherwise: $\gamma(\tilde{\varphi}l, \bar{\varphi}m)=\gamma(\hat{\tilde{\varphi}}l, \hat{\bar{\varphi}}m)$. Then, according to the first case, $\gamma(\hat{\tilde{\varphi}}l, \hat{\bar{\varphi}}m)$ is educed.

According to the two cases, we consider $\tilde{\varphi}l$ is similar to $\bar{\varphi}m$ if $\gamma(\tilde{\varphi}l, \bar{\varphi}m) \ge \frac{1}{2}$ otherwise not similar.

If there exists a certain kind of subsets in 95% or more of 8×8 blocks of a noisy image and these subsets are similar to each other, all elements of these subsets are regarded as corrupted pixels. Other noise pixels will be identified in next section.

2.1.3 Local Noise Detection

After the global noise detection, there are corrupted pixels that have not been identified. These corrupted pixels are as the remaining noise pixels among the uncorrupted one. Therefore, the local noise detection phase is used as follows.

An estimate of the original image from the noisy image is obtained by an adaptive median filter. The number of noise-free pixels in the filtering window for each pixel must be at least three. If the number is less than three, the window width should be increased by one pixel in each of the four sides and it repeats until the number reaches to three. P_{nos} and P_{med} denotes two pixel matrices of a noisy image and the estimated image respectively and $\Delta P=P_{med}-P_{nos}$ represents difference between these two images.

If ΔP_{sub} is an 8×8 matrix of ΔP and $\Delta P_{sub}(x,y)$ is an element of ΔP_{sub}, the threshold values can be defined as follows:

$$\Delta_{up}=\sqrt{\frac{1}{n_{sub}}\sum_{i=1}^{n_{sub}}(\Delta P_{sub}(x_i,y_i))^2}, \Delta P_{sub}(x_i,y_i) \ge 0 \quad (1)$$

$$\Delta_{low}=-\sqrt{\frac{1}{m_{sub}}\sum_{j=1}^{m_{sub}}(\Delta P_{sub}(x_j,y_j))^2}, \Delta P_{sub}(x_j,y_j) \le 0 \quad (2)$$

Where n_{sub} represents elements number of $\{\Delta P_{sub}(x_i,y_i) | \Delta P_{sub}(x_i,y_i) \ge 0\}$ and m_{sub} represents elements number $\{\Delta P_{sub}(x_i,y_i) | \Delta P_{sub}(x_i,y_i) \le 0\}$ .To detect noise pixels, the two proposed threshold values are used as follows:

If $\Delta P_{sub}(x,y)>\Delta_{up}$ and $\Delta P_{sub}(x,y)<\Delta_{low}$, pixel (x,y) is detected as a noise pixel.

2.2 Noise Removal

The phase of image filtering according to [1] is presented as follows:

In the first step, the initial filtering window size for each noisy pixel is selected 3×3. If the number of noise-free pixels in the filtering window is less than three, the window width should be increased by one pixel in each of the four sides and it repeats until the number reaches to three. In sequential iterations, each noisy pixel is replaced by the median of all pixels in the window. At the end of the first stage, noise pixels remaining in this step are replaced by median values resulting from applying a median filter with a 3×3 window width on the initial noisy image.

In the second step of image filtering noise mask Z(x,y) is defined in such a way that one and zero are applied to noise and noise-free pixels, respectively. Now, we can obtain the total number of residual noise pixels:

$$T=\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}Z(x,y) \quad (3)$$

By achieving this value, an accurate estimate of impulse noise level in the image can be obtained. So the ratio of noise pixels to total pixels of the image, which is a value between zero and one, is calculated from the following equation:

$$\partial=T/MN \quad (4)$$

By applying a filter on the input image I, the filtered image g is achieved.

$$g(x,y) = [1 - Z(x,y)]I(x,y) + Z(x,y)m(x,y) \quad (5)$$

Where Z is noise mask introduced in the previous stage and m is the median value obtained by the adaptive method for noise pixel. According to the algorithm presented in [1], to find m, for each pixel location (x,y) where Z(x,y) is equal to one, the following steps are performed.

- initializing the window width (W):

$$W = 2Rmin + 1,\ R_{min} = \frac{1}{2}\left[\sqrt{\frac{7}{1-\partial}}\right] \quad (6)$$

Computing the number of noise-free pixels located in the mask

- If the number of noise-free pixels in the window is less than 8, the window size is increased by 2 and return to previous step.
- Calculation of the m(x,y) value based on the noise-free pixels in the window.
- Computing the $g(x,y)$ based on Eq. 5.

After applying this algorithm finally, at the end of the second stage, the residual noise pixels is replaced by median values using a median filter, once with 5×5 and once with 7×7 window width, on initial noisy image.

3. Experimental Results

In this paper the size of the evaluated images is 512×512 and their intensity is 8 bit in gray scale. The results presented here indicate that the new filter is able to remove impulse noise specially more effective in high noise density and further details of the original image is preserved. In contrast to other methods that require repeating the algorithm at least twice to get the desired result, in proposed method the algorithm is applied just once, to get the desired result. Some standard criteria to evaluate the system performance in this field are defined for an M×N image as follow:

$$PSNR = 20\log_{10}\left(\frac{MAX_O}{\sqrt{MSE}}\right) \quad (7)$$

$$MSE = \frac{1}{M\times N}\sum_{i=1}^{M-1}\sum_{j=1}^{N-1}[O(i,j) - g(i,j)]^2 \quad (8)$$

Where MAX_O represents the maximum value of the original signal. $O(i,j)$ And $g(i,j)$ indicate the original image pixels and the filtered image pixels respectively. Table (1) indicates the results of implementation of the proposed algorithm on standard images Elaine, Lena and Boat with different noise density. In Table 2 the success of the algorithm compared to standard median filter, TMF [7], improved switching median filter (ISM) [9] and global–local noise detection-based adaptive median filter (GLAM) method presented in [12], is shown. Also in Table 3 comparing the performance of the proposed method with the results of the methods proposed in [16], [17] and [19] on Lena image in two different %40 and %60 noise density corroborate that the proposed algorithm provides better performance than the existing state-of-art impulse de-noising methods. Figures 1, 2 and 3 show the noisy images and filtered images for different noise densities. By increasing the noise density in images, error reduction and thus the success of the proposed method is more visible.

Also, the result of the proposed method in [17] and the result of our proposed method on Boats image with noise density of %60 are shown in Figure 4.

Table 1. Results of proposed algorithm on standard images Elaine, Lena and Boat with different noise density

	Elaine		Lena		Boat	
Noise Density	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**
10%	47.70	1.10	45.39	1.87	43.81	2.70
20%	44.58	2.26	42.21	3.90	40.74	5.47
30%	42.56	3.60	40.32	6.03	38.97	8.23
40%	41.11	5.02	38.99	8.20	37.66	11.12
50%	40.01	6.48	37.94	10.44	36.55	14.38
60%	38.88	8.40	36.95	13.09	35.71	17.44
70%	37.83	10.70	36.03	16.21	34.80	21.52
80%	36.90	13.25	35.22	19.53	33.97	26.05
90%	35.20	19.62	33.94	26.33	32.94	33.03
95%	32.89	33.39	32.32	38.08	31.53	45.69

Table 2. Comparison between the proposed method and other methods on the Elaine image with noise density of 80%.

		MSE	**PSNR**
Standard Median filter	5×5	1415.5	16.62
	7×7	409.55	22.00
	9×9	240.33	24.32
TMF [7]		402.61	22.08
ISM [9]		231.54	24.48
H.IBRAHIM [1]		214.62	24.81
GLAM [12]		59.68	30.37
OUR METHOD		13.25	36.90

Table 3. Comparison between the proposed method and other methods on the Lena image

Noise Density	**[16]**	**[17]**	**[19]**	**Proposed method**
%40	31.45	31.79	34.91	38.99
%60	27.02	28.80	31.81	36.95

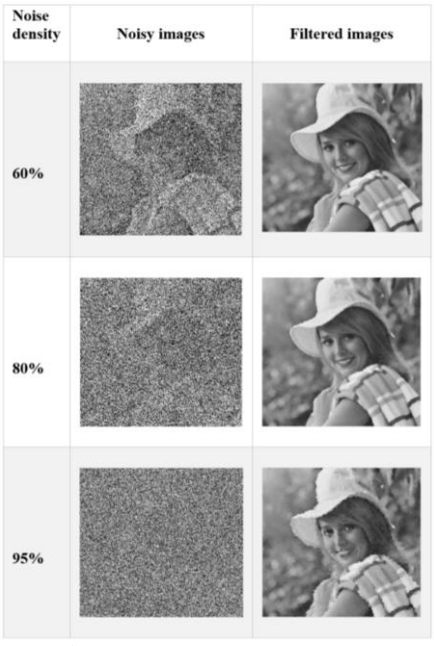

Fig. 2. Results of proposed algorithm on corrupted images of Elaine

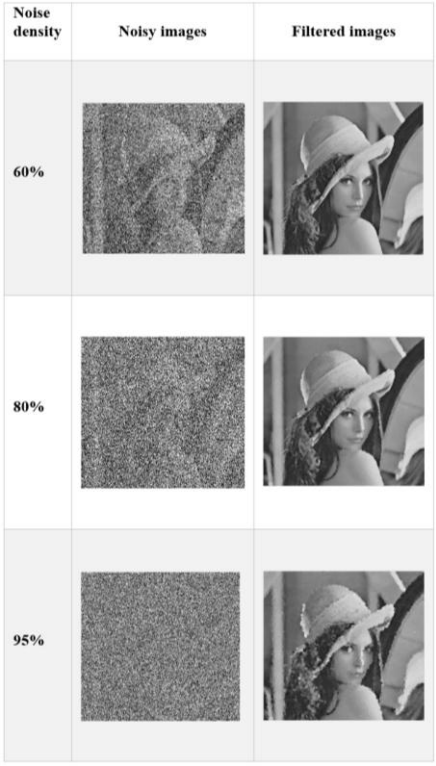

Fig. 3. Results of proposed algorithm on corrupted images of Lena

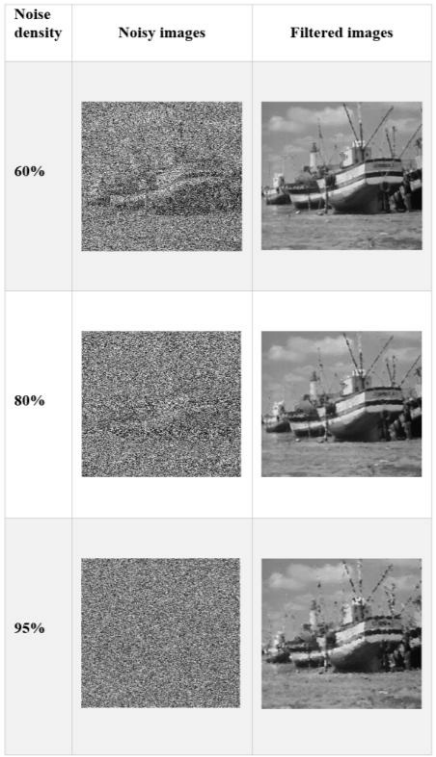

Fig. 4. Results of proposed algorithm on corrupted images of Boat

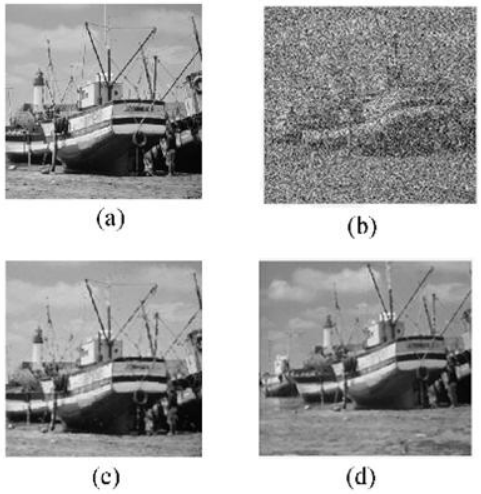

Fig. 5. comparing results on Boats image, (a) original image, (b) 60%noisy image, (c) result of [17], (d) result of proposed method

4. Conclusion

In this paper, a new algorithm for impulse noise removal from digital images is proposed. The algorithm uses a logical combination of previous proposed global-local noise detectors and adaptive median filters to achieve better results. The implementation results on different standard images show the success of proposed algorithm in comparison to other proposed methods.

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ANFIS Modeling to Forecast Maintenance Cost of Associative Information Technology Services

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Received: 23/Feb/2017 Revised: 21/Nov/2017 Accepted: 11/Dec/2017

Abstract

The model in this study was created to apply a new and functional model for prediction of IT maintenance cost of system downtime by using artificial intelligence method in contrast of other research techniques in IT cost measuring. The estimation is based on the measuring of IT services availability. In this model, ANFIS was developed for quantifying Information Technology Generated Services (ITGS) perceptible by business users. In addition, it was used to forecasting IT cost related to system maintenance that it can help managers for future and constructive decision. This model has been applied and tested prediction technique by ANFIS in MATALB fuzzy toolbox by previous large volume of data gathering from IT cost factors, ITGS, and associative cost in order to building pattern, tuning and training this model well. First of all, the model was fully developed, stabilized, and passed through intensive training with large volume of data collected in one of the organization in Iran. In first phase, it can be possible to feed a specific period of data into the model to determine the quantity of services (ITGS), and in second phase, their related maintenance cost can be predicted. ANFIS learning technique predicted maintenance cost of measured services availability which it was totally provided with first quantifying services in a specific time period. Having an operational mechanism for measuring and quantifying information technology services tangible by users for estimating their costs is contributed to practical accurate investment. Some components have been considered and measured in the field of system maintenance. The main objective of this study is prediction the amount of investment for maintenance of entire ITGS by extraction and considering the factors affecting the software maintenance cost help to estimate the cost and reduce it by controlling the factors.

Keywords: Information Technology; ANFIS Modeling; IT Generated Consumable Service; Intangible Cost; Availibilty; IT Cost Factors; Maintance Cost.

1. Introduction

Determining amount of investment and budgeting for each year, especially in new technologies including IT is heavily complicated. IT creates a lot of cost for organization if IT managers do not have enough knowledge and information related to cost management. Therefore, right recognition of cost factors and effective factors can be associated to cost prediction in the area and also great support to the cost-effectiveness of any enterprise. IT investment has a positive effect on technical effects on the firms production process (Ko et al., 2006). The increasing dependence of many businesses on IT and the high percentage of IT investment in all invested capitals in business environment (Jafari, 2013) are essential functions which should be considered within every organization providing possible solution and services expected to assess the achievement of business objective. The first step in IT investment is to know exactly what that investment is and measuring and tracking this expenditure over time against a convenient base (Cunha et al., 2014). If the cost follows an industrial standard, it enables the organization to have right understanding for enough investment in the area of IT in a specific period. The growth of revenue via offered technology solution enables organization to achieve strategy business goals and level of competitiveness. In order to assess achievement level related to such expectation, mechanism has to be determined. Researchers and practitioners have expressed concern about cost, benefit, and quality of software documentation in practice (Vahid et al., 2014). In this article, IT cost is estimated for system maintenance phase by quantifying IT services availability tangible by users. Having available information enables organization to determine how much maintenance cost has been spent for IT services with consideration of their sub-components. To achieve these goals, it is necessary to develop a model based on experimental and historical data utilizing ANFIS modeling. In the past decades, numerous studies have been published on software cost estimation method including expert judgment, parametric models, and at least machine learning (Huang et al., 2015).

The availability of a system under failure /repair process is a function of time which can be determined through a set of integral equation and usually calculated

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numerically (Alireza Daneshkhah, 2013). Availability is a key parameter which quantifies system performance. This parameter is closely related to reliability. The difference between these two concepts is that reliability refer to failure-free operation during an interval, while availability refers to failure –free operation at a given instant of time. (Philippe Ezran, 2017) . In the study, services availability of IT services was predicted numerically by the number of downtime and service lost in system.

Performance improvements in maintenance activities are ususally measured by avaiability and oprtaional reliability indicators. They should be obtained preserving maximum quality and safetly levels and minimizing the costs. (Aitor Arnaiz, 2013)

Mavaahebi and Nagasaka (2013) applied a model using neural network with simulation data for estimation of all IT services' value quantified by IT cost factors connected with some IT service channels. However, the authors in the study applied an ANFIS model which permitted the usage of neural network topology together with fuzzy logic in an organization with real data based on previous authors' suggestion. Additionally, innovative objective is the forecasting maintenance cost as target with consideration of six available IT services values measuring. This model can be suggested and designed as a new model implemented in monitoring systems of the use-case organization considered as significant innovation with incorporation of IT services quantification and cost estimation, concurrently practical in IT field. The reason that authors used ANFIS is that it not only includes the characteristics of both methods, but also eliminates some disadvantage of their lonely –use case. Operation of ANFIS looks like feed-forward back-propagation network. Consequent parameters are calculated forward, while premise parameters are concluded backward. In this article, backpropagation learning in neural section is applied. Output variables are obtained by applying fuzzy rule to fuzzy set of input variables in Takagi-Sugeno inference system.

Adoptive Neuro fuzzy inference system model provides the learning feature of neural network along with the easy interpretability characteristic of fuzzy model make it suitable for predication and modeling of complex systems. The results showed that the proposed model is a powerful technique and valuable tool for forecasting variables from known and achieved knowledge which is not easily measured. In this paper, the results of modeling are shown in which the ANFIS is used for quantifying generated consumable services of IT (ITGS) to show the level of effectiveness of IT activities and also forecasting of their maintenance cost. Neuro-fuzzy inference system adapted to the Takagi-Sugeno known as a fuzzy model was used for these models. ANFIS is trained with a volume of data to quantify the services with fuzzy data. Four fundamental components utilized and applied in maintenance channel and system lost include human resource, technology/infrastructure, and process and system downtime considered as IT cost factors and normally tracked in any organization and feed to model. All four variables include some components with diversity and difference in each organization related to their activity.

The paper is organized as follows: in first section introduces the background of our work by providing a brief introduction to model. In section 2, provides with related work of other approaches and suggested models for IT cost measuring. In section 3, we describe proposed model and framework of ANFIS applied in a use case. Conclusion remarks are given in section 4.

2. Related Works

Various approaches and models have been applied to describe software value measurement and also quantifying IT software cost. Among those approaches, some were statistical approaches for their measurement and fewer studies included artificial intelligence. In this paper, Neuro–fuzzy systems (ANFIS) use fuzzy rules which allow modeling fuzziness and ambiguity in modeling environment and are capable of dealing with uncertainly and complexity in the given data set, and it has shown interesting results in modeling non-linear function (V. Majazi Dalfard et al., 2013). Some of the approaches include Bootstraps and Neural network prediction models developed by Sonmez (2011) to estimate the construction costs. Neural network is applied as an appropriate modelling tool to calculate the complicated relations between components and costs. They also used Bootstrap as a method for prediction of variables definition. In that study, they utilized a method for easy evaluation of the parameters' effect on cost for cost estimation; therefore, they were able to investigate easily the amount of uncertain levels on cost evaluation.

Marsh and Flanagan (2000) studied the measure of the costs and benefits of IT implemented in construction industry. They came to conclusion that the evaluation of costs and benefit presumably derived from the application of IT reflects available data at the point of evaluation. They argued that some difficulties in quantifying benefit associated with improved information availability prevent IT cost and benefit analysis effectives.

Dugan et al. (2002) introduced life cycle costs for IT. The life cycle of the components can be generally addressed to be distributed in this manner: initial cost including investigation, recognition, acquisition, installation, training, and recursive cost. It would be helpful when budgeting in successive fiscal year, including training, maintenance, evaluation, upgrading, migration, and replacement. Dugan et al., (2002) found that how much cost is needed to maintain the existing integrated system. Furthermore, they suggested and constructed a model for budgeting IT regarding evaluation, upgrading, migration, and replacement. This cost model was applied toward software, hardware, information resource, and services to support IT infrastructure such as network.

Y- Cheng-Tang (2009), developing fuzzy analysis hierarchy process and artificial neural network,

investigated cost allocation for an aerospace company. The applied model was addressed to use the proposed policies evaluation including tangible and intangible information and a comparison made between FAHP and ANN. In his study, allocation efficient budgeting is a fundamental principle in job flow and developing benefits in company. Neural network modelling applied in the paper addresses an intelligent and powerful technique with non-liner relation for recognition of the complicated patterns. ANN model has self-learning ability by adjusting the parameters to reduce the error of estimation. ANN is a mathematical or computational model based on biological neural network. Much of the research on ANN has focused on accounting, finance problem, bankruptcy, and fraud detection. In the article, the ability of ANN leaning for data training in ANFIS is used.

Irani et al. (1998) directed cost which may also include unexpected additional hardware accessories such as increase in processing power, memory, and storage device. Meanwhile, they considered indirect cost as largely divided into human and organizational factors. Indirect cost was defined as moving from old to new activities by consideration of new system effects; initial hardware software costs, system development, training, and maintenance were considered as direct cost. However, they associated indirect cost with IT and information system implementation including management, staff resource employee training, and motivation time. Love et al. (2004) stated that on-going costs including maintaining, modifying, and application incurred from year to year and account for as much as 91 percent of lifetime cost of software. Also they found that managers tend to overestimate the initial costs like hardware, software, system development costs, and estimation on-going cost, and as a result, a huge gap between estimated allocated budget and actual costs in an organization. They argued that a major difficulty was associated with IT budgeting related to identification of costs, especially those with indirect nature. They proposed a two-tire system for clarifying indirect human costs. The first tire refers to management, employee, finance, and maintenance. Management decides on the amount of IT expenditure. Employee refers to all people related to issue in organization; finance refers to allocation of budget, and maintenance refers to development and implementation of IT. Maintenance costs in contrast to Irani's proposal are considered as indirect cost his paper. For the accessibility of IT, Culnan (1985) suggested that perceived accessibility is likely to be influenced both by the context of use and earlier experience with source. But in her study, she stated nothing about the dimension of accessibility and progression use of particular information source.

Availability estimation methods for IT services can be classified as qualitative and quantitative approaches as well as black-box and white-box approaches. qualitative approaches such as expert interviews are rather subjective and hardly transferable, quantitative black-box or data-based methods utilize availability data, e.g. of monitoring tools, in order to estimate future service availability quantitatively However, these approaches require suitable data sources that may not be accessible in the service design stage (Sascha Bosse, 2015). Therefore, in the study method, service availability of the system used quantitative input to estimation, leading to white-box or analytical approaches.

Leyland *et al.,* (2012) proposed the SERVQUEL model as an appropriate instrument for researcher seeking a measure of information system service quality. SERQUEL measures tangibility, reliability, responsiveness of SERVQUEL suitability assessed in three types of organization in three countries. Kumar *et al*., (2015) argued about defects' removal effectiveness to improve the software quality fault prone analysis, presenting solution of parameters in linear regression model with cost estimation method. While the model in this study is managed by taking into account earlier studies information to apply a new and functional model for IT maintenance cost estimation using artificial intelligence method in contrast of other research techniques in IT cost measuring. This estimation is based on the level of availability of IT services in the organization. Also with different view of earlier studies toward measuring system availability by a new and intelligent tool of ANFIS, good results obtained for both estimation of IT cost and quantification of IT availability.

3. The Proposed Method

Neural – fuzzy modelling refers to applying various learning techniques developed in the neural network literature to fuzzy modeling or fuzzy inference system. Neural-fuzzy systems which combine neural network and fuzzy logic recently have gained great interest in research and application (Dalfard et al., 2003). Fuzzy inference systems are a rule base system consisting of three conceptual components. They are: (1) a rule –base containing fuzzy if-then rules (2), a data-base, defining the membership function, and (3) and inference system which combines the fuzzy rules and produces the system results. A specific approach in neural –fuzzy development is the adaptive neural-fuzzy inference system (ANFIS) which has shown significant results in modeling nonlinear function (Dalfard *et al*., 2003), and it is used in solving various problems. The reason why ANFIS applied in the article is retaining both methods' advantages and outweighing disadvantages. The lack of fuzzy inference system is solved by creating knowledge about a problem from neural inference system training data while the complicated and hard to understand rules of neural networks are bypassed using linguistic variable by means of which results are easily explained (Svalina *et al*., 2013).

The learning procedure and construction of the rules are provided by back propagation algorithm. The performance of ANFIS modeling, both training and testing data, is evaluated in this study. And the best

training / testing data is selected according to Root Mean Square Error (RMSE), Standard Deviation (SD), and Error Mean (EM) (shown in table 2) . The fuzzy inference system of Takagi-Sugeno type is known as a systematic approach which can be considered as an adoptive neural fuzzy inference system similar to neural network in which by training the system on input/output data set, the parameter of the fuzzy inference membership function or antecedent parameter and the parameter of Takagi-Sugeno fuzzy system output function or consequent parameter are adapted (Svalina *et al.*, 2013). Takagi-Sugeno system applies the function that gives real number as outputs. The set of inputs and the relationship between outputs and inputs is defined by if-then rules.

Two rules for first order Takagi-Sugeno fuzzy inference system may be stated as:

Rule1: IF x is A1 AND y is B1 THEN z is f1(x, y)

Rule 2: IF x is A2 y is B2 THEN Z is f2(x, y)

Where x and y are ANFIS inputs, A1 and B1 are fuzzy sets, and f (x, y) is a first order polynomial and represents the outputs of the first order Takagi-Sugeno fuzzy inference system. Figure 1 shows the process and steps of ANFIS development as below (Prasad *et al*., 2016).

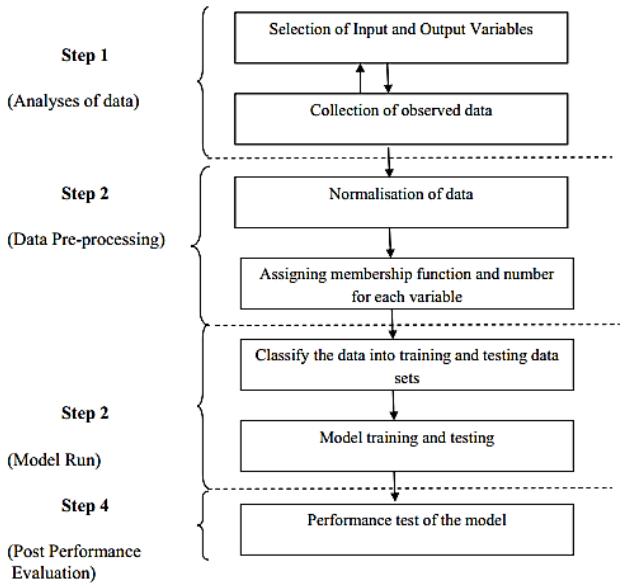

Fig. 1. Flowchart of ANFIS model

The present work demonstrates the development and application of ANFIS technique for quantifying IT services applied in the first model and also forecasting maintenance cost including tangibility and intangibility in the second phase of modeling by consideration of the measured services values as input (Figure 2). Nero-fuzzy system combines neural network and fuzzy logic which recently have gained great interest in research and application (V. Majazi *et al.*, 2013). ANFIS uses the learning ability of ANN to define the input-output relationship and construct the fuzzy rules by determining the input structure.

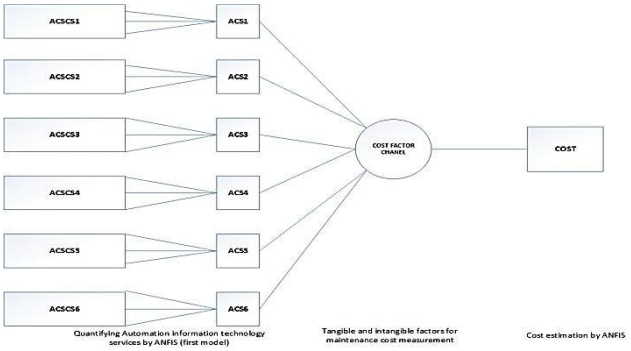

Fig. 2. The conceptual model

The process flow for building relationship among various factors related to IT services and its maintenance cost of the service are shown in Figure 2. Each block in the diagram represents the activities needed to collect data from the organization. And blue blocks determine the activities performed by Neuro-fuzzy inference system (ANFIS). The activities in the left white blocks are surveyed independently and are needed to collect data. However, there are a few blue blocks developed by ANFIS modeling. Quantifying IT services is associated with collecting data of their attributes in organization to measure their availability. However, the forecasting of maintenance cost is related to quantifying IT services.

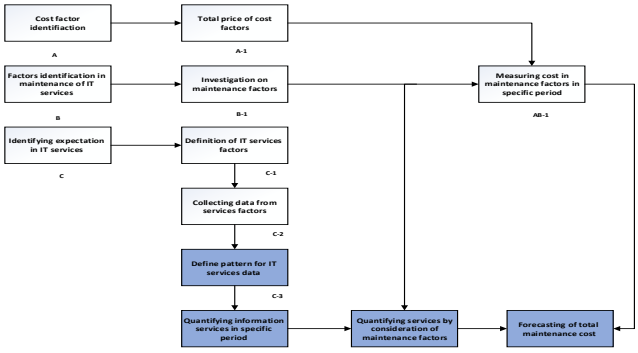

Fig. 3. Work process flow

The primary objective of the study was to develop ANFIS model for the first quantification by selection of optimum attributes as inputs for six main variables as outputs collected in use-case organization (Table 1).

$ACS_i = f\ (acs_{ai}, acs_{bi}, acs_{ci}, acs_{di})$

Where:

$acs_{a, b, c, d}$ = system availability services inputs

ACS_i= outputs

Table 1. Component of availability of IT services

Availability of consumed services in IT	Symbol	Number of attributes
System availability services	ACS1	4
Data availability services	ACS2	4
Application response time availability services	ACS3	3
Service support availability services	ACS4	3
Network availability services	ACS5	4
Turnaround time availability services	ACS6	3

Each output contains some measurable sub-components (attributes) to reach the value of outputs. One-year data was collected to be used for training and

testing ANFIS model. Sub-components (attributes) of each variable were identified and collected in the organization research.

There are some characteristics of the model as well as steps required to be fulfilled listed below:

1. It would be necessary to identify sub-components (attributes) of IT services availability.
2. Leveraging historical data to build a model to quantify availability of IT services from identified measurable sub-components within organization
3. Identifying and allocation of consumed ratio relationship between maintenance costs and consumed IT services
4. Identifying maintenance cost components and the severity of the impact of downtime and system failure influence
5. Conclude the cost of lost due to downtime and fault in services.
6. ANFIS model can be developed for quantifying IT services by collecting historical data in organization and also for forecasting the maintenance cost by building relationship between cost and maintenance factors.

4. Case study

4.1 Quantifying of Automation Information Services

In developing ANFIS model for quantifying six main variables of IT services for quantifying in future application, automation services of one of the Iranian state-run organization was studied; some automation services attributes were indicated within organization which were the reasons of downtime and service failure. After historical data was collected and normalized in rang of [0 1], they were trained with several steps iteration to reach minimum error in MATLAB toolbox. Grid partition was used in order to establish the rule-base relationship between the input and output variables. Grid partition divides the data space into rectangular subspace using axis-paralleled partition based on pre-defined number of membership function and their types in each dimension (Prasad *et al.*, 2016). Among some membership function types, Gaussian membership function is used in the cases. As it is shown in Figure 4, each of the six variables is concluded in both data training and testing. Seventy percent of data was applied for training data and 30 percent for testing data (Table 2). The number of attributes of each variable might be different in each organization or company related to the field of their activities. Figure 4 shows the plot of training and testing data developed by ANFIS for the service support variable as a sample to show among those six introduced variables.

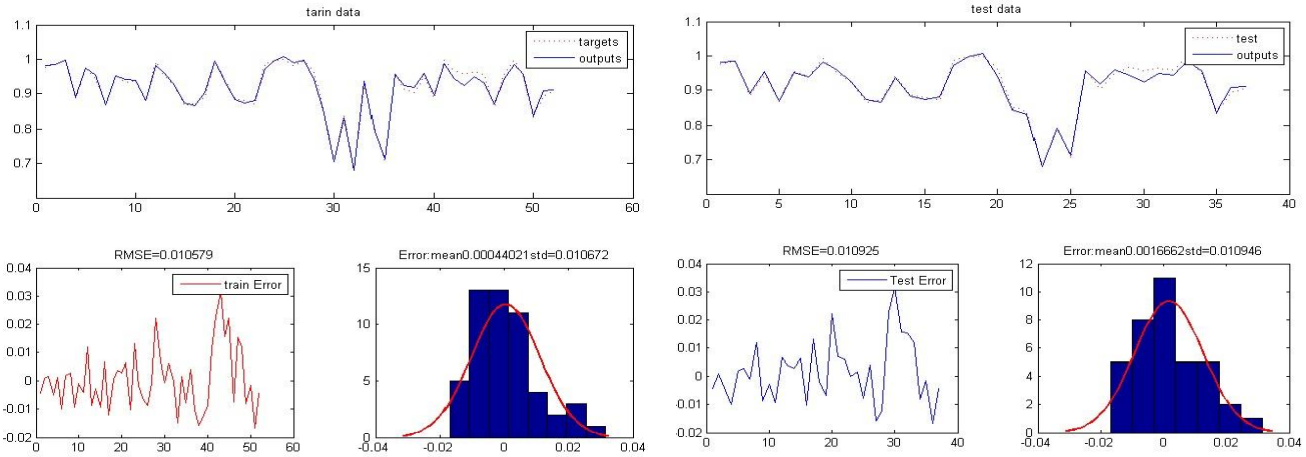

Fig. 4. Train and test data for service support availability

Table 2. Quantifying services of automation

Variables	Data type	Number of inputs membership function	Epoch	EM	RMSE	STD
ACS1	Train	4	250	0.00044	0.0105	0.0106
	Test	4	250	0.00166	0.01092	0.01094
	Check	4	250	0.0059	0.01346	0.01247
ACS2	Train	3	250	0.00031	0.00933	0.00941
	Test	3	250	0.00011	0.01009	0.0102
	Check	3	250	0.00105	0.00781	0.00795
ACS3	Train	5	250	0.00012	0.00385	0.00388
	Test	5	250	0.00050	0.00347	0.00348
	Check	5	250	0.00058	0.00448	0.00457
ACS4	Train	3	350	0.00044	0.01057	0.01067
	Test	3	350	0.00166	0.01092	0.010946
	Check	3	350	0.00590	0.013464	0.01247
ACS5	Train	4	250	0.0060	0.01331	0.01343
	Test	4	250	0.00060	0.0123	0.01246
	Check	4	250	0.0027	0.0149	0.0150
ACS6	Train	3	250	-8.889	0.00905	0.00914
	Test	3	250	0.00013	0.00966	0.00981
	Check	3	250	-1.114	0.00766	0.00808

4.2 The Maintenance Cost Forecasting for the Automation Services

In this study, also the well applicability of ANFIS as forecasting the maintenance cost of those measured services was investigated. This model was applied to calculate the maintenance cost of automation services in specific period regarding to consideration of failure cost of six variables in addition to fix maintenance costs including (human, train, and process). Maintenance cost is associated with the availability of services calculated in the first model.

In this model, every input variable might be clustered into several class values to buildup fuzzy-rule in the first layer. Each fuzzy rule is constructed in Gaussian membership function through two parameters in layer 2. The reason to choose clustering in the model is to prevent any complexity and unfair results due to increment in the number of parameters and fuzzy rules. Collected data was normalized in range of [0 1] before being fed into the model. The normalized data sets were divided into both training and testing data as well as first model percentages. According to finding, ANFIS reach to best result with minimum error close to real data for both training and test data. As it is show in table 3, forecasting cost, close to real cost, surveyed and confirmed by related experts. And also achieved services target of table 4 in contrast with output of measuring IT service has minimum and acceptable error .they confirmed by related experts in the field.

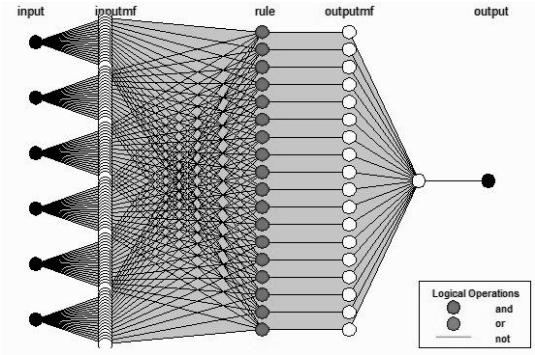

Fig. 5. ANFIS model for cost forecasting

Table 3. ANFIS output for cost forecasting

Test number	Real cost (ml/r)	Forecasting cost (ml/r)
1	436	424
2	732	746
3	685	689
4	667	662

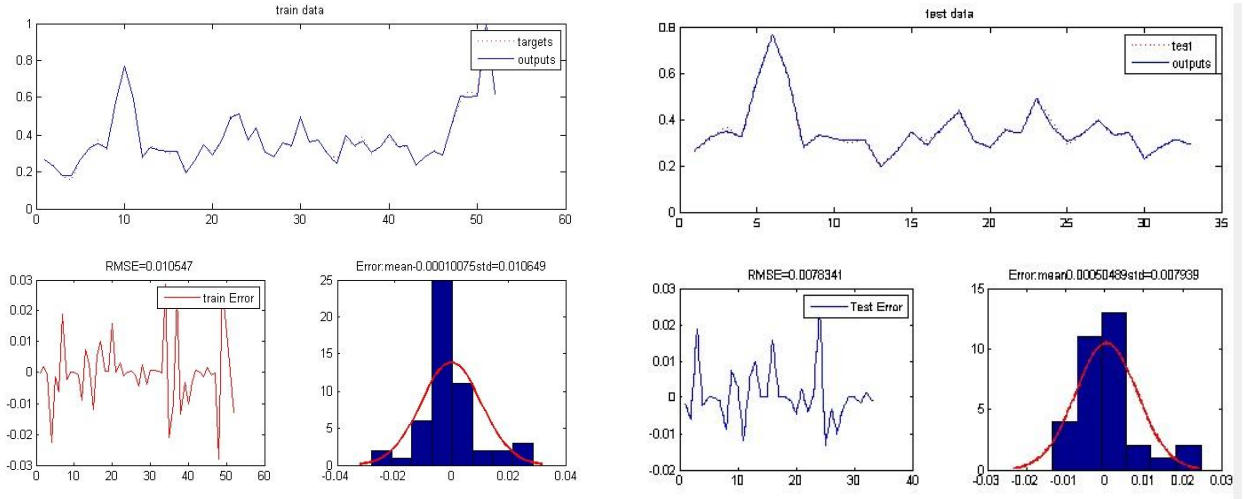

Fig. 6. train and test data for cost forecasting

5. Conclusion

Nowadays, the measurement of accessibility and availability of IT services for IT administrators and also consideration of their associate costs are essential factors for future oriented decisions from the capability of the system based on user expectation to accurate investment in the field.

Accurate investment in IT is complicated for some IT administrators based on the number of current services in their organization. Identification of new artificial intelligence methods will help them to know the level of effectiveness of IT services in their organization in each period. In the present study, to prove and verify proposed prediction framework MATLAB fuzzy logic toolbox is used. This tool provides us with ANFIS as a selected learning technique to present and develop the model in two phase: first phase is quantifying the level of IT services' availability (6 variables), and second phase is prediction of their maintenance cost of system failure by finding of six variables measurement of services. To prevent any complexity for data collection resulting from large number of services, Automation System placed in System Maintenance department of study organization was selected as a user-involved and widely-used system to find out indicators, affective reasons and implementation of the model. And also this department helps us to estimate lost maintenance costs and find its effective indicators. The results of some tests are shown in Table 3, and also Table 4 indicates that ANFIS can predict with minimum error close to real number. Regarding to result of this paper, ANFIS can predict well with lowest fault

and near to real data. It is kind of effective, new, practical technique than other with precise prediction.

As for future work, (1) the model can be developed as a basic suggestive model to measure other kinds of cost related service quantification; (2) it is practical for the under-study organization to develop a management module in monitoring systems by combination of both models' targets discussed in the article. It provides managers with views to check constantly the status of the system and the reasons of increased cost to be applied in future decisions; (3) more advanced method can be involved in the experiment as regression; (4) extensive experiment on more variables and attributes can contribute to more realization.

Table 4 shows the outputs of the model with respect to forecasting of cost and quantifying IT services studied in automation services in the organization in specific periods.

Table 4. Outputs of ANFIS training

Table1: Inputs and outputs of ACS1					
MF	HT	HDF	NDF	Target	Output
87.3	100	95.2	89	93.1	94
Table 2: Inputs and output of ACS2					
TS	CL	LCS	NR	Target	Output
99.6	97.3	96.5	92.2	97.3	97
Table 3: Inputs and output of ACS3					
EM	GT	HR		Target	Output
99.9	99.9	99.7		99.9	99.9
Table 4: Inputs and output of ACS4					
RTP	RTN	RTO		Target	Output
62.5	89.8	100		98.3	97.9
Table 5: Inputs and output of ACS5					
PT	ST	ND	BT	Target	Output
98.2	96.5	95.7	99	96.2	96.3
Table 6: Inputs and output of ACS6					
TI	AR	DR		Target	Output
85.5	86.7	72.2		83.7	84.7

Table 7: Inputs and output of cost							
ACS1	ACS2	ACS3	ACS4	ACS5	ACS6	Target	Output
93.1	97.3	99.9	98.3	96.2	83.7	1411	1419

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