A Novel Approach for Establishing Connectivity in Partitioned Wireless Sensor Networks Using Beamforming Techniques

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Abstract

Network connectivity is one of the major design issues in the context of Wireless Sensor Networks (WSNs). Due to diverse communication patterns, some nodes lying in high-traffic zones may consume more energy and eventually die out resulting in network partitioning. This gives rise to a situation when some alive nodes are trapped in a disconnected cluster and do not have enough radio range required to communicate their data to destination, i.e. to a sink or a relay node connected to the main part of the network. This phenomenon may deprive a large number of alive nodes of sending their important time-critical data to the sink. In this paper, we propose a virtual antenna based cooperative beamforming approach in order to retrieve valuable data from these disconnected nodes. In the proposed scheme, the sensor nodes in isolated partitions work together to form a directional beam which significantly increases their overall communication range to reach out a distant relay node connected to the main part of the network. The proposed methodology of cooperative beamforming based partition connectivity works efficiently if an isolated cluster gets partitioned with a favorably large number of nodes. Furthermore, we propose a cooperative beamforming based scanning mechanism to search for the nearest alive node connected to the main part of the network. The proposed mechanism is then elaborated through simulation results. The simulation result shows that our proposed mechanism achieves upto 70% partition reduction through beamforming as partition healing.

Keywords: Wireless Sensor Networks (WSNs); Connectivity Restoration; Network Partitioning; Cooperative Beamforming; Fault Recovery.

1- Introduction

Wireless sensor network (WSN) consists of a large number of small nodes, deployed in a target area, for various purposes such as environment monitoring, security surveillance and medical diagnoses, etc. In a wireless sensor network, data transmission is achieved through multi-hop communication, in which the sensor nodes relay their data through neighboring nodes to the sink. Although this method is energy efficient, yet it has limitations [1][2]. The sensor nodes depend on each others for the routing of their data to the sink. Thus a single dead node may lead to a significant change in the network topology. Hence even a cluster of alive nodes may stop communicating with the sink and thus gets disconnected.

Beamforming is a technique by which an array of antennas can be steered to transmit radio signals in a specific direction. Rather than simply broadcasting energy/signals in all directions, the antenna arrays that use beamforming, determine the direction of interest and send/receive a stronger beam of signals in that specific direction. This technique is widely used in radars and sonar, biomedical, and particularly in communications (telecom, Wi-Fi), specially 5G – Where very high data rates are required and the only way to support this would be to maximize transmit and receive efficiency by using beamforming.

In this technique, each antenna element is fed separately with the signal to be transmitted. The phase and amplitude of each signal is then added constructively and destructively in such a way that they concentrate the energy into a narrow beam or lobe.

In order to deal with such phenomenon, we propose the cooperative beamforming mechanism to increase the effective communication range of the isolated partitions. We also propose a cooperative beamforming based scanning mechanism to search for the nearest alive node connected to the main part of the network containing sink.

2- Related Work

In recent years, cooperative communication through beamforming attracted the attention of a large number of researchers worldwide. Many schemes have been proposed for beamforming [3-7] and its effective use in energy efficiency [8-11], power optimization [12] and node localization [13]. However, to best of our knowledge this the first attempt to use cooperative beamforming for partition healing in a wireless sensor network.

The authors in [3] proposed the idea of cooperative communication through the nodes equipped with the smart antenna. They propose the methodology of cooperative communication between nodes to form a Multiple-Input and Multiple-Output (MIMO) link for enhancing diversity and data rate of the network. The technique uses the intelligent adaptive antenna system instead of Omni directional antennas.

The distribution of wireless sensor nodes in an area of interest in relation to their collaborative beamforming is discussed in [4]. The paper investigates the challenges such as the orientation and distribution of sensor nodes for their efficient collaborative beamforming. It uses a Gaussian distribution function to model the spatial distribution of sensor nodes.

In [5] the effectiveness of the beamforming has also been studied with respect to different sensor node distribution models. The paper shows that collaborative beamforming provides better performance when sensor nodes' deployment follows a Gaussian Probability density function (pdf) as compared to uniform pdf. The authors in [6] proposed a method to determine the minimum connectivity probability for a given transmission range with respect to any node density with varying antenna beam-width of a smart antenna system mounted on special purpose wireless sensor nodes. With this method, they found the minimum number of smart nodes with various beam widths required in a given region. The phase synchronization of the transmitted waves over time-varying channels has been discussed in [7]. The authors propose a method which uses continuous feedback from a receiver to optimize the phase of transmitting waves to form an effective beam. In [8] the authors analyze the behavior of cooperative beamforming for the varying number of nodes involved and type of antenna installed on sensor nodes.

In [9], a convex optimization framework is used for collaborative beamforming to increase the network lifetime and to satisfy a predefine quality of service (QoS). Similarly, in [10], a cooperative beamforming mechanism is investigated to perform energy efficient communication. The result shows that with an increase in the number of cooperative nodes, the energy efficiency is improved for cooperative transmission, but more energy would be needed for sensor selection and beamforming. In [11], a scheduling algorithm has been proposed for data transmission using beamforming. Experimental results are presented which shows that the beamforming achieve more transmissions than direct or multi-hop transmissions. A convex optimization framework which optimizes the collaborative and distributed beamforming is presented in [12]. In [13], the node selection for cooperative beamforming is made in coherence with a uniform circular array. The idea of cooperative communication for wireless sensor network node localization is presented by [14]. The authors propose a method to solve localization issue by cooperative communication among the nodes.

Furthermore, the re-connectivity issue of the disconnected nodes in partitioned networks has been addressed extensively in the literature not only through static redeployment but also by partition filling with mobile nodes. In [15] the authors proposed Distributed Prioritized Connectivity Restoration Algorithm (DPCRA). The algorithm use recovery information stored in each sensor node. This information is updated periodically to recover from network partitioning. In [16] the author proposed a sleep scheduling based energy conservation technique to prevent network partitioning. [17] Proposed an iterative exact algorithm to solve the connectivity problem. They used combinational optimization in their proposed approach. In [18], the authors targeted a special network partitioning scenario. i.e, environmental constraints (rain, fog etc) can reduce a sensor communication range, which may result into network partitioning. The proposed technique address the problem through adjusting the sensor communication range.

Wang et al. in [19], presents a redeployment mechanism by finding out the most vulnerable cluster sets where redeployment can contribute in prolonging the network lifetime. The author propose heuristic algorithms and expectation based prediction approach to solve the redeployment problem. Bhatt et al. [20] use the Markov process to find out the probability of node redeployment and apply stochastic processes for recovering holes in the network. Authors in [21], propose a two-phase redeployment technique for identification of disconnected partition in a sensor field. After identification, a mechanism for network reconnection is provided, which finds an optimized location for new nodes to be redeployed.

In [22][23], authors address the network partitioning problem through additional relay node deployment. In their research, the focus is on finding the optimal number of relay nodes and identifying the suitable location for these additional relay nodes to be placed. similarly in [24], the partitioning problem is also addressed through efficient redeployment of additional relay nodes using concentric format points. In [25], two fault tolerant algorithms were proposed to restore connectivity through additional relay node deployment. The proposed algorithms utilizes minimum convex hull technique to obtain optemized number of additional nodes to be used, along with their respective deployment position to achieve network connectivity. [26] propose deployment of long distance routing sensor nodes to overcome connectivity problem among different segments of wireless sensor network. In the above-discussed approaches static node redeployment was the focus of research, researchers main focus was to identify three basic parameters. 1) when to redeploy the additional nodes. 2) number of required sensor nodes. 3) location calculation for the redeployment of additional nodes to overcome the network partitioning.

The main drawback of those approaches is that it still required additional resources to heal the network partitioning since redeployment is a time-consuming activity and becomes inappropriate for time critical data application.

In [27] the authors propose an Obstacle-avoiding Connectivity Restoration Strategy (OCRS) for mobile nodes based wireless sensor actor network. They also highlight the constraints related to node relocation. The authors in [28], presents a relocation mechanism, for mobile sensor nodes to repair a partitioned network. They discussed the relocation of the mobile node to fill in the void space among separated segments of the network, by taking into account its degree of connectivity with the neighboring nodes. In [29] the authors proposes a Distributed Connectivity Restoration Strategy (DCRS) to deal with network partitioning. They discuss a mechanism to identify an appropriate backup node for every critical node in the network to replace the failed node in case of network partitioning. To deal with the dis-connectivity among different segments of partitioned network a distributed reverse constrained recovery (RCR) mechanism is presented in [30]. They use mobile sensor node which acts as a relay node to recover connectivity. Similarly, in [31] mobility aware special sensor nodes called mobile data collectors (MDC) are proposed to overcome network partitioning. The paper presents an obstacle aware connectivity restoration strategy (OACRS). This strategy utilizes, Optimize obstacle avoiding spanning tree mechanism to determine the minimal number of MDC nodes required and their respective positions to recover the connectivity. In [32] the authors consider the realistic view of deployment region, i.e terrain variation to determine optimal path for mobile nodes displacement to cover the void area, which cause network partitioning.

To summarize, the existing methods in literature, for reconnecting a disconnected network, mostly rely on topological changes in the network. Which is both time and resource consumingactivity. Therefore, these techniques cannot be used for important time-critical data. There is a significant chance of losing important real-time data sensed by the disconnected sensors. Furthermore, the existing techniques cannot be used to form a robust network for reliable sensing in time-critical situations such as security, and environment monitoring in mining industry and forest fire prevention etc.

2-1- Problem Statement

An intensive study of antenna radiation patterns and beamforming mechanisms enables us to exploit its directed power dissipation property to achieve large effective communication range. It has been observed that a collection of nearby nodes equipped with single omni directional antennas, if work together in a collaborative manner by combining their transmission powers to form a single directed powerful beam that can effectively increase their communication range. If this collaborative beamforming technique is used by the cluster of disconnected nodes can increases the transmission range thereby skipping the dead hops or the dead relay nodes and directly communicating with the sink to reconnect the disconnected clusters.

The organization of the rest of the paper is as follows, In section 2 proposed methodology along with the system model is explained. The simulation results and evaluation are demonstrated and discussed in section 4. Section 4 concludes the paper.

3- Cooperative Beamforming Based Partition Re-connectivity Mechanism

3-1- System Model

Consider a wireless sensor network that consists of multiple nodes deployed over an area of interest. They sense their surrounding and forward sensed data to some central repository called a sink or gateway for further processing. Sensor nodes are low-powered vulnerable devices equipped with limited-power batteries and omnidirectional antennas to send and receive signals. All sensor nodes are homogeneous with same initial energy. Communication between any source node and sink is done in hop by hop manner as shown in Fig. 1. It was assumed that each node is aware of his neighboring node/s

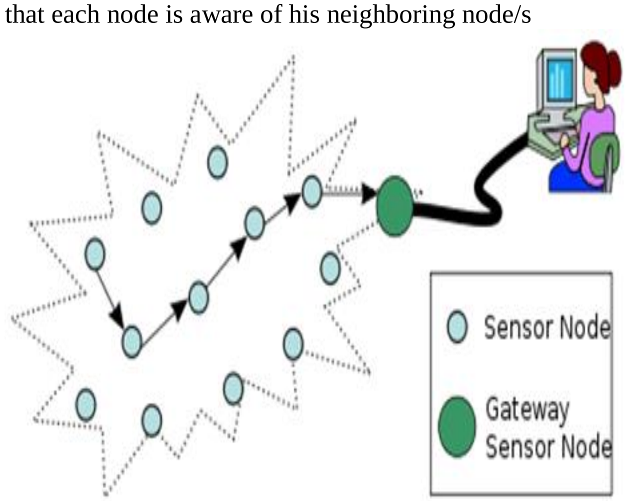

Fig. 1. Multihop Communication in WSN

3-2- Problem Formulation

As packet transmission consumes energy, some nodes being on the frequently used paths are more critical than those present on such paths which are either not at use or minimally used. If such nodes get involved in data transmission, there is a high probability that these nodes would result into dead nodes due to depletion of the rest of their energies. This leads to the formation of disconnected clusters as shown in Fig. 2.

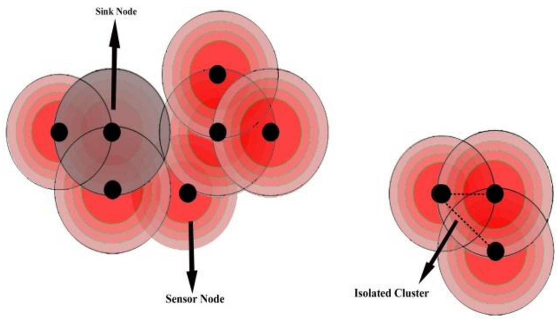

Fig.2. Isolated Cluster in Wireless Sensor Network

When such cut occurs in the network, data packets sent by the source nodes are stopped at the nodes presented on the boundary of the disconnected clusters and no acknowledgment are received at the transmitting nodes. Meanwhile, the sink is unable to fetch any information about the data been sent by the nodes present in the partitioned cluster. Situation become worse when the partitioned cluster contains sufficiently-power nodes that become unable to connect individually nearby node, already connected to the main network. This situation arises mostly in large networks, where low power nodes have limited communication ranges. In order to relay important data contained/sensed by the nodes present in the disconnected cluster to sink, a communication link is needed. Establishment of this communication link is the main contribution of this research work. We propose a cooperative virtual smart antenna mechanism, in which the nodes present in the disconnected cluster collaboratively form a directional beam toward any nearby alive node connected to the main part of the network. This arrangement will enable them to transmit data to the high-powered sink which will unicast the acknowledgment of the reception directly to the source.

In virtual smart antenna (VSA) system, the transmitters are fitted with single Omni-directional antennas rather than multi-element smart antennas. These single antenna transmitters work collaboratively to attain the features of a multi-element smart antenna. While working in a cooperative manner, the antenna of each individual node acts like a smart antenna element. This virtual smart antenna technique can work efficiently in WSN environment, where the transmitting nodes have no longer distance among them. They can transmit the data to distant receiver by using collaborative beamforming as shown in Fig. 3.

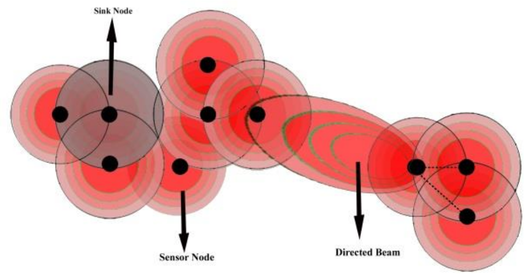

Fig. 3. Proposed Cooperative Beamforming Based Partition Reconnectivity Mechanism

3-3- Cooperative Beamforming

A network would be said partitioned whenever the packets sent by the source are accumulated at a specific node on the path from the source to sink and the said node is not able to get further acknowledgments from its receiving relay node ahead of it on the path towards sink. Such node would then initialize cooperative beamforming procedure with the co-ordination of its neighboring nodes. A node that initiates beamforming would be considered as the reference node and its distance to the prospective receiving relay node would be taken as the x-axis of the frame of reference. In order to form a directional beam, the transmitted waves of the transmitting nodes should be received in phase at the receiver for their constructive summation. Nevertheless, the nodes of isolated cluster deployed in 2D planar area are not in an array form and they do not have equal spacing among themselves. As an example a disconnected cluster of three nodes N1, N2 and N3 is shown in Fig. 4. These nodes aim to send their data to a receiving relay node R.

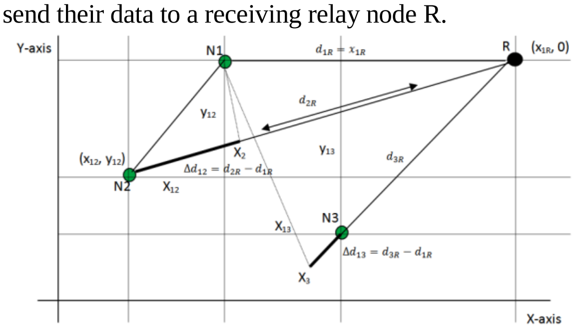

Fig. 4. Working of the Proposed Cooperative Beamforming Mechanism.

Since three of the transmitting nodes know their physical locations, therefore they will easily arrange their phase adjustments according to their locations in order to form a co-operative beam towards any prospective receiver R. If these nodes start transmitting the same signal without phase adjustments, out of phase versions of these signals would be received at the receiver which would cause destructive interference. The obvious cause of this destructive interference is the path difference of the waves transmitted by the nodes located at different physical locations. However, if the to-be-transmitted waves are preprocessed at two nodes in accordance with the reference node before their transmission towards receiver, the corresponding destructive interference can be converted into an in-phase summation resulting into an enhanced power at the receiver.

Let the paths taken by the waves transmitted from N1, N2, and N3 respectively as shown in Fig. 4. Since N1 is taken as the reference node, it thus becomes the center of the x-y co-ordinate system. In order to form cooperative beam towards the receiver R, both of N2 and N3 should align their transmitting waves to that of N1 by using phase adjustment strategy; so that all waves should receive in-phase at R. As the exact location of R is unknown, therefore the reference node N1 will have to visualize its location with the assumption that it may lie anywhere around it at a distance d1R much larger than its transmission range. In order to ensure that signals transmitted by the disconnected cluster should reach at R, the beam range should be equal or more than d1R. However, the beam range strictly depends on the number of nodes that take part in the cooperative mechanism [3], i.e.

$$d_{1R} \le N d_0 \tag{1}$$

where N is the number of total neighboring nodes taking part in the collaboration including the reference node and is the range of transmission of a single node. It is worth mentioning that if is larger than even the cooperative beam would not be able to reach R and the disconnected cluster would never be able to send its data to the sink. It would thus remain disconnected from the main part of the network. Therefore, the initial distance between reference node N1 and the prospective unknown receiving relay node R would be set on the maximum beam range [3], i.e.

$$d_{1R} = N d_0 \tag{2}$$

Direction of the unknown receiving node from the reference node N1 is also very important for directive beamforming. In the next section, we will present a detailed note on finding the direction of the receiving relay node and getting connected to it for data transmission. At the moment, we assume that R resides at any arbitrary direction from N1. As already discussed, the separation between N1 and R is set as the reference x-axis of the coordinate system, as shown in Figure 4. Considering the geometry drawn in Figure 4 and manipulating some basic calculations, the distance and can also be calculated [5] as

$$d_{2R} = \sqrt{\left((x_{1R} - x_{12})^2 + (y_{12})^2\right)} \tag{3}$$

$$d_{3R} = \sqrt{\left((x_{1R} - x_{13})^2 + (y_{13})^2\right)} \tag{4}$$

Where and because of N1 being the reference node set at origin with along the x-axis. The same mechanism can be utilized to find the distance between the receiving node and transmitting node, taking part in the beamforming mechanism as

$$d_{NR} = \sqrt{\left((x_{1R} - x_{1N})^2 + (y_{1N})^2\right)} \tag{5}$$

From the geometry shown in Fig. 4, and are the differences in the distances traveled by the waves transmitted from N2 and N3 with reference to N1, respectively [5].

$$\Delta d_{12} = d_{2R} - d_{1R} \tag{6}$$

$$\Delta d_{13} = d_{3R} - d_{1R} \tag{7}$$

In general, can be calculated for any node N as [5]

$$\Delta d_{1N} = d_{NR} - d_{1R} \tag{8}$$

This distance disagreement covered by the wave transmitted from the node N as compared to the one transmitted from reference node N1 will cause a phase difference at the receiver. Magnitude of this phase difference can be calculated [5] as

$$\Delta \phi_{1N} = 2\pi f_c \left(\frac{\Delta d_{1N}}{c} \right) \tag{9}$$

Where f_c is the operating frequency and is the velocity of light. If we can pre-process the corresponding phase difference at any node with reference to node N1 before transmission, we can have all waves received in-phase at the receiver despite of their path differences. In other words, we can say that all nodes, taking part in the collaborative mechanism, will become able to form a strong beam ideally times of the power of a single node. Hence they will be able to transmit data with enhanced transmit diversity availing much longer range. This will also improve the bit error rate of the communication link. In this way, the nodes in the disconnected cluster will become able to form a cooperative beam towards any closest node attached to the main part of the network.

3-4- Getting Connected to the Network

After forming cooperative beam, the nodes in the disconnected cluster would still not be able to connect to the main part of the network, if they do not know the direction in which the nearest relay node (already connected to the main part) resides. We present the following mechanism to address this problem. When the nodes of the disconnected cluster become able to generate a strong beam which covers a longer distance, they start scanning the whole area around them for possible existence of an alive relay node which may connect them to the main part of the network. The sequence of steps needed to perform this function are shown in Algorithm 1. In this algorithm, the reference or source node in the disconnected cluster transmits beacon messages in narrow beams in all directions (in a clockwise or anticlockwise manner). The beacon message contains two type of information; one that the beamforming flag is enabled and the second is about the time slot at which the beam is formed in the respective direction. The flag will tell the receiving node about the special circumstances of partitioning due to which the message has been generated through cooperative beamforming.

Algorithm 1: Cooperative beamforming based scanning procedure at the source side for searching any alive node that is connected to the main part of the network.

```
θ ⟵ 0;                                      /* Initialil beam direction */
BF-flag ⟵ 1;                                /* Set the beam flag to true */
repeat
    Time-slot⟵ getSystemTime(); /* set the time slot corresponding
    to the beam direction */
    Hello-Msg ⟵ BF-flag + time-slot;                   /* Beacon message */
    transmit(hello-Msg);
    θ ⟵ θ + 1;
until θ ≤ 360;
Ack-msg⟵ listen(Ack);      /* Listen for acknowledgemet from the
sink */
if Ack-msg=Null then
    quit();              /* Failure: No alive relay node in range */
else
    Success-Angle ⟶ extract(Ack); /* Success: alive node in range
    at angel θ */
    transmit(Data-packet);              /* Start data transmission */
end
```

Algorithm 2: Procedure followed by the sink on successful reception of beacon message generated through cooperative beamforming.

```
Max-RSSI ⟵ 0; timeThreshold ⟵ 2×RTT; /* Set the time threshold
to twice the length of round trip time */
for i=0 to timeThreshold do
    Rcv-msg=listen(hello-mesg);        /* Wait for beacon message */
    if BF-flag=true;                        /* Check the beam flag */
    then
        Rcv-RSSI ⟵ extract(Rcv-msg);    /* extract RSSI information
        from the received message */
        if Rcv-RSSI > Max-RSSI;              /* Look for maximum RSSI */
        then
            Max-RSSI ⟵ Rcv-RSSI;
        end
    end
    Max-RSSI-msg ⟵ Rcv-msg;
    time-slot ⟵ extract(Max-RSSI-msg);      /* Extract the time slot
    corresponding to the beam direction from the message received
    with maximum signal strength at the relay node */
end
transmit(Ack times-slot);     /* Send acknowledgement with time slot
corresponding to the successful beam angle */
```

If any relay node, connected to the main network, receives any of these beams containing specific information (BF-flag), it will measure the received signal strength (RSSI). The RSSI is transmitted to sink along with the received message. The procedure followed by the sink on the successful reception of the message generated through cooperative beamforming is explained in Algorithm 2. As the sink may receive many messages arriving via multiple relay nodes with different beam power level information (RSSI). It will select the node with the highest RSSI as a valid relaying agent for communication with the disconnected cluster. The time slot information (time-slot) contained in the beacon message having highest RSSI will identify the successful beam direction at the source node. The sink will acknowledge the receipt of the highest RSSI beacon message by sending acknowledgment directly to the disconnected cluster along with the time slot (time-slot). The time slot will help the cluster to set the respective direction corresponding to the successful beam as the valid direction for future communication. The reference node in the cluster also working as the cluster head will ask the other nodes participating in the cooperative beamforming mechanism to lock their phase adjustment with respect to the successful time slot for future communication with the main part of the network. The sink may receive the cooperative beam directly without getting hopped by any relay node. However, the same procedure of acknowledgment will be followed. Upon successful completion of this process, the isolated cluster will be able to send the important time-critical packets accumulated at different reference nodes to the sink.

4- Results and Discussion

The proposed scheme is evaluated with respect to received power enhancement to ensure network connectivity by partition healing using cooperative beamforming.

A number of simulation using MATLAB 10 is been performed, such that each simulation is run for 10 times each. The data points were taken as an average of 10 simulation runs to ensure the result precision. The simulations were run over sensor nodes distributed uniformly over an area varies from (500 x 500) to (4000 x 4000), keeping the number of nodes and their communication range constant. This enables us to analyze the performance of the proposed scheme at different node densities. For better understanding beside detail experiment setup, we present a simple experimental setup of simulation field of 100 comprising of 50 sensor nodes. The initial deployment is random and each node has a constant communication range but varying data rate as shown in Table 1.

Table 1: Nodes Data Rate

No of Nodes	Data Rate (Kbps)
19	> 50
14	> 40 and < 50
12	> 30 and < 40
5	< 30

The change in topologies with variable data rate leads to network partitioning due to the dead node labeled 39 as shown in Fig.5.

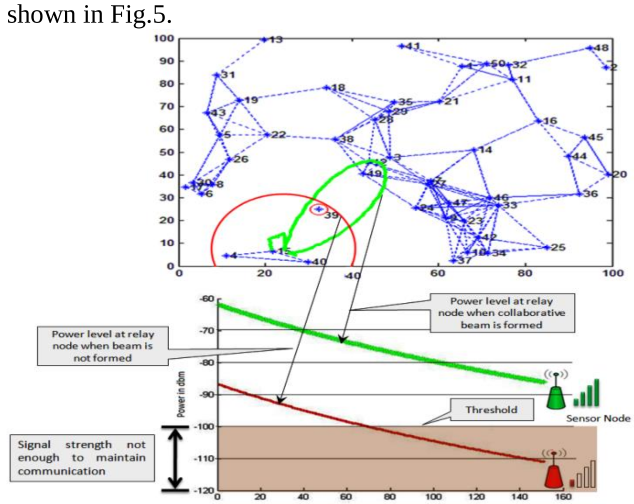

Fig. 5. Power analysis of the cooperative beamforming as compared to individual node transmission in the disconnected cluster.

The elimination of the node 39 causes the cluster of nodes 4,15 and 40 to partition and disconnect from the main part of the network. A cooperative beamforming mechanism is thus executed which results into the generation of high power beam. Furthermore, Fig.5 depicts the cooperative power analysis of the scenarios, when beamforming is available, or not in term of distance between the transmitter/s and the relay node. The result shows an exponential decrease in received power of the signals transmitted individually by the node 15 with increasing distance and eventually, these signals become undetectable at the closest relay node numbered 49. However, cooperative beam formed with the cooperative effort of all three nodes in the disconnected cluster becomes able to reach the relay node and thus resume the communication.

The varying degree of partitioning is required to comprehensively evaluate our proposed technique. There for detail evaluation, we took a comprehensive simulation setup comprising of 300 nodes with varying simulation area as mentioned in Table 2.

Table 2. Simulation Parameters for comprehensive setup.

Simulation Parameter	Value
Area	500x500 to 4000x4000m2
Simulation tool	MATLAB
Communication Range	100m
Node Distribution	Uniform Random
Number of Simulations	10

The results are obtained with varying node density to achieve different degree of partitioning. We execute our scheme of partition healing if a reference node (the one that initiate beamforming) has more than one neighbors. A significant reduction in number of disconnected isolated partitions can be observed in Fig.6 as an average of ten round each. We can observe the number of disconnected partitions with and without using beamforming approach. At the simulation area between 2000m2 to 2500m2 the difference between the curve is quite significant. Which mean that beamforming mechanism was successful enough to heal good number of partitions (work better with compact large size partitions). This is because the efficiency of our proposed approach rely on the number of participating nodes in cooperative beamforming. Similarly, as we increase the simulation area the difference between the curves decreases and they appear to converge. This is because the average node density tends to reduce with increase in simulation area resulting into single node partitions, which our technique cannot able to handle. Fig.7 shows a percentage improvement in partition healing. The curve shows that we can achieve up to 70 % reduction in network partitioning if isolated partitions have sufficient number of nodes to participate in cooperative beamforming. Fig.8, describe the network efficiency in term of number of successful packet recived. This indicate that the network remain stable for longer period of time. Therefor maintaining high network connectivity we can achieve greater throughput and avoid critical data lose.

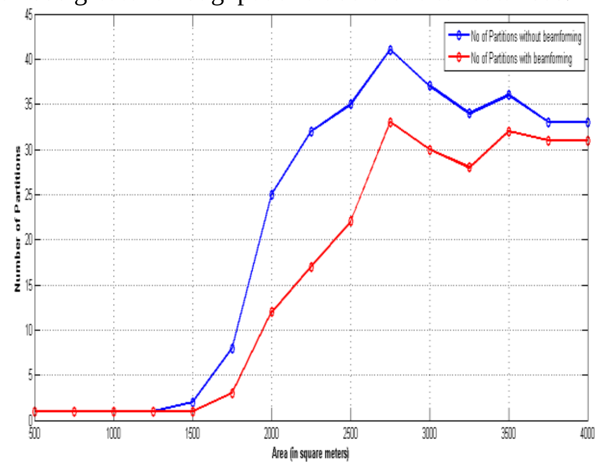

Fig. 6. Partition Development/creation with and without using Beamforming

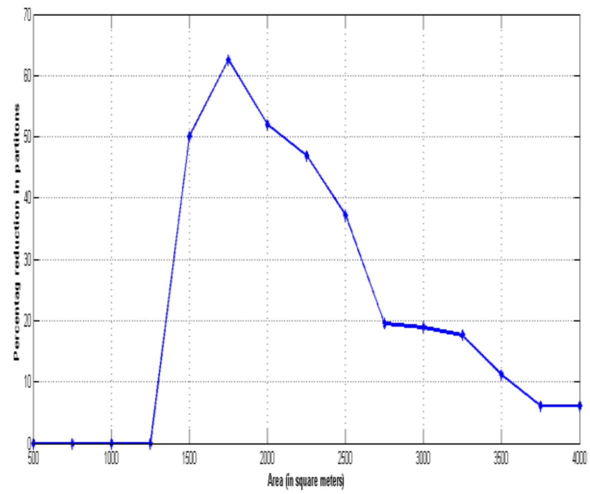

Fig. 7. Percentage reduction through beamforming as healing

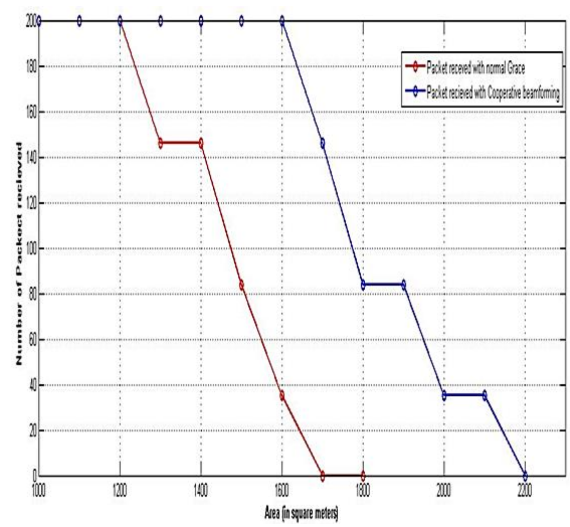

Fig. 8. Packet delivery ratio, with and without beamforming

5- Energy Efficiency

To verify the performance of the presented method, ExOR and EEOR algorithms are chosen as the comparison in order to analyze the transmission reliability and energy consumption performance of opportunistic routing algorithms. The main simulation parameters are set out in Table 3.

Table 3. Simulation Parameters

Parameter	Value	Parameter	Value
Monitoring area	200×200 (m^2)	ε_f	10 (pJ/b•m^{-2})
Number of nodes	100 (#)	E_{tx}, E_{rx}	50 (nJ/b)
E_0	0.5 (Joule)	l	400 (bit)
d_{TH}	50 (m)	p_{ij}	0.1~0.9
d_{THL}	40 (m)	d_{THH}	50 (m)

In the simulation scenario, 100 nodes are accidental implemented in the target destrict, and 10 independent random deployments are carried out respectively, and the performance simulation is performed respectively. In each random deployment, 10 pairs of nodes are randomly selected as the source node and the target node, and each pair of transceiver nodes repeat 10 opportunistic routing and relay selection. The average is taken as the simulation result.

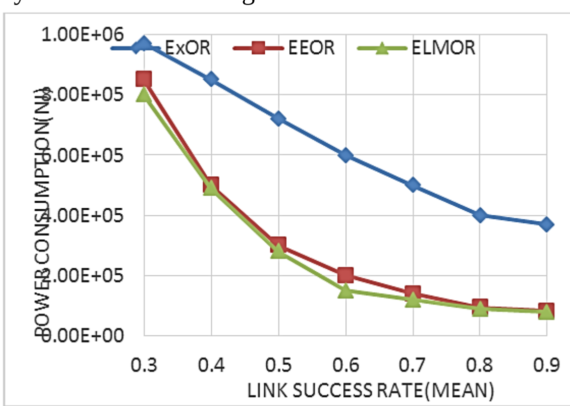

Fig. 9. Power consumption based on link success rate

In one probability aware region nodes have a consistent connected probability P_{ij}, change the value of P_{ij}, the single hop energy consumption of a successful transmission is shown in Fig.9. It is obvious from the graph that the single hop transmission power consumption of the three algorithms decreases with the increase of the success rate of single hop transmission. The reason of this may be the retransmission of failure is becoming less as the link quality goes high. The one hop energy consumption of ExOR algorithm drops approximately linearly. However, when the transmission reliability is low, the single hop energy consumption of EEOR and ELMOR algorithm decreases rapidly, and the energy consumption tend to be flat after the success rate of single hop transmission is more than 70%. On the whole, the single hop power consumption of ExOR is significantly higher than two other algorithms, while the single hop transmission energy consumption of ELMOR is almost the same as EEOR. Also, transmission energy consumption of EEOR with one hop success rate is higher than 0.7.

6- 5- Conclusion

In this paper we have proposed a cooperative beamfroming approach in order to retrieve valuable data from the nodes trapped in the disconnected cluster of a wireless sensor network. In the proposed scheme, the sensor nodes in isolated partitions work together to form a directional beam which significantly increases their overall communication range to reach out a distant relay node connected to the main part of the network. It has been shown that the proposed methodology of virtual smart antenna based cooperative beamforming for partition connectivity work efficiently, if an isolated cluster gets partitioned with favorably large number of nodes. Graphical illustration have been presented that depict how virtual smart antenna based cooperative beamforming can increase radio range and received signal strength. furthermore, a mechanism has been developed that enables a disconnected cluster to form cooperative beam and locate a nearest relay node for its reconnection to the main part of the network. Thus it enables a wireless sensor network to minimize critical data loss in case of network partitioning and provides a robust solution for data critical wireless applications.

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