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Effective Connectivity for Sparse and Dense Wireless Sensor Networks

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Abstract: In Wireless Sensor Networks (WSNs), multi-hop routing is generally used for data forwarding from the source to the destination. A major problem with this mechanism is that failure of connectivity between the source and destination. This study presents a technique to ensure better connectivity called Transmission Range Tuning (TRT). The TRT approach tunes the transmission range of a node to discover its neighbor node. If it is not able to discover its neighbor with the initial transmission range, it increases the transmission range at the rate of double. The node repeats this process till it receives a reply. The chief advantage of the proposed TRT scheme is that, it can be applied on both the sparse (TRT-S) and dense (TRT-D) scenario. The distance between neighboring nodes in a sparse WSN is much larger than their transmission range. Most of the previous works on the sparse WSN depend on a particular mobile element for data exchange and connectivity. TRT-S approach achieves connectivity in the sparse network on increasing the initial transmission range of a node. In a dense network, the dense WSN schedule its process to prolong the network lifetime and ensure energy conservation. In the scheduling process, a reduction of active nodes results in loss of connectivity. TRT-D scheme ensures connectivity and conserves energy in the dense WSN. This study presents a simulation based performance evaluation of TRT that ensures connectivity at minimal loss of energy and lifetime in both sparse and dense scenarios.

Key words: WSN, sparse, dense, transmission range, connectivity and energy conservation

INTRODUCTION

A WSN is a distribution of sensors in a definite area for the purpose of monitoring and collecting some set of data. It monitors physical or environmental scenarios like temperature, humidity, sound and pressure at various locations (Tubaishat and Madria, 2003). The WSN finds its application especially in military (battlefield surveillance). Now-a-days, the application of WSN extends to industrial process monitoring, machine health monitoring, home automation, environment monitoring, healthcare applications and traffic monitoring. The basic functionalities of the WSN are monitoring, tracing and controlling (Xu, 2013).

There are several constraints in the WSN as in wireless ad hoc networks. In most of the cases, coverage and network lifetime cannot be obtained to the maximum extent simultaneously (Cardei and Wu, 2004). To obtain a better coverage range, deployment of more number of active sensors is necessary. In such a case, the sensor consumes more energy, resulting in reduced network lifetime. Furthermore, to achieve a better network lifetime, most of the active sensors are switched to sleep mode, resulting in partial coverage. Achieving better network lifetime and coverage range is still a serious issue in the sparse WSN. It is much difficult to predict the requirements of the network lifetime that varies according to the application. Most of the existing solutions satisfy the coverage range requirements regardless of network lifetime constraints. Some coverage oriented approaches are suggested in the literature. The major drawbacks of these approaches are redundant coverage that results in wastage of energy resources. It significantly affects the lifetime of the network that may even terminate the entire communication system.

The WSN usually consists of several sensors deployed over a physical region. According to the application requirements, the sensor may be deployed in two fashions such as dense deployment and sparse deployment. In a dense deployment scheme, a large number of sensors are deployed within an area. In a sparse deployment scheme, only a few sensors are deployed. Some scenarios prefer the dense deployment scheme where every event to be monitored or area to be

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covered using several sensors. When an application considers the cost of the sensors, the sparse deployment is the better choice. Sparse deployment achieves maximum coverage of sensor nodes with the help of few nodes. Most of the real time sensors applications do not prefer a fine grained sensing (Akyildiz *et al*., 2002).

In a sparse WSN, smaller transmission range is maintained. Therefore, the nodes in a sparse WSN cannot communicate directly with each other. Moreover, in such a network, multi-hop communication becomes impractical. An intermediate centre is needed between the two sensors in the sparse WSN. A special Mobile Element (ME) achieves communication between the two distant sensors in a sparse WSN (Shah *et al*., 2003). ME is a node that often visits sensor nodes, collect data and transfer it to the sink node. Based on the environment (external or networking infrastructure) of the application, ME may be a car, bus, humans and animals and may be mobile robots in networking transportation. A mobile element can have any form of mobility pattern. The sparse networking majorly finds its application in environmental monitoring. In many cases, only a moderate number of sensor nodes (distributed sparsely) are enough to meet the application requirements. The sparse coverage supports coverage holes that focus on covering a small area as much as possible.

In the dense WSN deployment, the density of sensor node is high over a given area. This allows random deployment in a critical region. In the dense WSN, cooperation among the nodes is necessary. The distances between any two neighboring nodes are short and close to each other due to the dense deployment of a large number of sensors. Therefore, this sensor network exploits multi-hop communication. The problem in a dense network is that, nodes in the dense WSN schedule its process to prolong the network lifetime and ensure energy conservation. In the scheduling process, a reduction of active nodes results in loss of connectivity.

This study suggests a technique called TRT to ensure connectivity in the WSN. Tuning the transmission range so as to discover a neighbor node is the principle of TRT. The neighbor discovery process accompanies broadcasting of a beacon message with an initial transmission range. If a node could not discover its neighbor with its initial transmission range, it increases its transmission range at a rate of double using TRT scheme. The transmission range of a node is tuned till it finds its neighbor. Both the sparse and dense network can exploit the TRT scheme. A loss of connectivity is a general problem in both the sparse and dense WSN. TRT ensures connectivity in both sparse (TRT-S) and dense (TRT-D) scenarios.

Problem statement: In a WSN, connectivity of sensors is the crucial issue. In the previous context of providing connectivity in WSN, it proves that the communication range must be twice of the sensing range. A major issue is the loss of connectivity in the WSN. Achieving connectivity is still a serious concern in both the sparse and dense WSN. In the sparsely connected WSN, a store and the forward technique ensures the availability of data to the sink. This technique introduces additional data latency. The use of special mobile elements (vehicle, animal, human) is the alternative for a store and forward technique. Existing solution for ensuring connectivity in the sparse WSN considers special mobile elements. The proposed work does not consider special mobile elements for achieving connectivity in a sparse network. On the other hand, dense WSN also faces some issues. In some cases, full coverage cannot be achieved to guarantee the lifetime of the sensor networks. Thus, better lifetime results in a partial coverage of the nodes. There are some scheduling algorithms like partial coverage scheduling algorithm that affects connectivity due to the insufficient number of active nodes towards the sink. Therefore, a solution proposed for achieving connectivity in the sparse network is also applicable for the dense WSN. The proposed work suggests a technique called TRT that ensures connectivity in both the sparse and dense WSNs.

LITERATURE REVIEW

Connectivity in WSN: In a sparse WSN, multi-hop routing forwards the data from the source to destination. The cooperative transmission technique suggested in (Krohn *et al*., 2006) connects a previously disconnected area of the network. This scheme reduces the number of nodes that are necessary to ensure full coverage. In cooperative transmission, sensors combine transmitting power with neighbor sensor resulting in increased transmitting range. The cooperative transmission improves both connectivity and coverage, especially in sparse network settings. The four-connectivity scheme overcomes the drawbacks of two connectivity patterns. It achieves four-connectivity and full coverage under varying coverage and sensing range (Bai *et al*., 2008a). The major drawback of this approach is that it does not investigate the long path problem.

A group of the pattern develops 3D WSN that ensures maximum coverage and k-Connectivity. Achieving full coverage in a 3-D WSN with a minimum number of sensors under low connectivity is still an open issue. Another major issue in 3-D WSN is the optimal deployment pattern of sensors. It proposes a new sensor deployment approach which maintains optimality of deployment (Bai *et al*., 2009). It ensures 1-connectivity and 2-connectivity approaches using lattice.

Coverage in WSN: An effective approach proposed in (Lambrou *et al*., 2010) develops a system with a reduced number of stationary sensors that will often collaborate with a set of mobile nodes. The mobile sensors coordinate their own movements to cover the uncovered area of the static sensors and hence, facilitate collaboration among static sensors. The mobile nodes adopt a dynamic path planning algorithm to collaborate among static sensors.

Achieving scalability becomes an issue in the real world deployment. Trap coverage is a novel technique that ensures a well scale over a large deployment area (Balister *et al*., 2009). The coverage hole is a portion of an uncovered area in the target deployment region. A sensor network provides trap coverage only if the diameter of the target region is equal to the coverage hole. Trap coverage scheme, senses every movement and displacement of an object within the target region. The major issue in this scheme is that, it may require a large number of sensors to meet the higher level requirements.

The Probabilistic Coverage Protocol (PCP) mainly considers two sensing models, namely, the probabilistic exponential sensing model and commonly used deterministic disk sensing model (Hefeeda and Ahmadi, 2007). PCP activates only some of the deployed sensors to build an approximate triangular lattice on top of the target area. In WSN, the scheduling technique is much effective in achieving energy conservation. A unique protocol called Coverage Configuration Protocol (CCP) dynamically configures the sensors for attaining definite degree of coverage and connectivity (Wang *et al*., 2003). It incorporates the suggested protocol, the CCP with SPAN to achieve a greater degree of coverage and connectivity. The major drawback of the solution is the computational complexity.

A technique by Li and Cassandras (2005) suggests a distributed coverage control for cooperating mobile sensor networks. This technique is incorporated into the sensors deployed in a disaster relief mission. A gradient algorithm acquires information among each sensor locally. This information detects the occurrence of random event probability. This involves in trading off the sensing coverage and cost of communication in terms of power consumption. Consider a coverage guaranteed network in which investigation of the connected coverage area is still a serious issue (Liu and Liang, 2005). The concept of partial coverage is analyzed for ensuring longer network lifetime.

Sensor deployment schemes in WSN: An optimal sensor deployment pattern suggested in (Bai *et al*., 2008b) achieves full coverage with 3-connectivity and 5-connectivity in a WSN. A hexagon based universally elemental pattern generates all other connectivity patterns. A novel deployment polygon based technology proves the optimality of this approach. The optimality of a regular pattern is achieved if Rc/Rs = 1. An effective technique by Bai *et al*. (2006) achieves 2-connectivity and 1-connectivity.

An artificial bee colony algorithm deploys the sensor in a dynamic pattern that achieves better performance in terms of the coverage area (Ozturk *et al*., 2012). A foraging attitude of honey bee swarms is the key principle of this algorithm. It works effectively especially in numerical optimization and clustering approaches. Sensor dispatch deals with the movement of a subset of sensors to a particular region so as to meet coverage and connectivity requirements (Wang *et al*., 2008). This approach supports a planned deployment of sensors. It deploys sensors in an arbitrary-shaped sensing field with arbitrary-shaped obstacles. It derives an arbitrary relationship among communication and sensing range. This feature makes it differ from other deployment approaches.

Achieving barrier coverage in a WSN is a serious concern, especially in the application like border surveillance and intrusion detection. It divides the sensor deployment scheme into several rounds (Yang and Qiao, 2010). This technique effectively handles the placement errors with these multi rounds of sensor placement. Moreover, the two round minimax approach and the pilot deployment approach are suggested where the residence of the sensor is not known completely. A recursive algorithm overcomes the issues in the minimum set covering problem (Xu *et al*., 2005). This approach classifies the nodes in the network as sensing nodes, relaying nodes and base stations.

Mobile node discovery using dual beacons: In a sparse WSNs, the special mobile nodes facilitate a collection of data. An efficient discovery protocol suggested in (Kondepu *et al*., 2011) uses two various beacon messages emitted by the sensors. The two different beacon messages are Long Range (LR) beacons and Short Range (SR) beacons. LR beacon indicates the existence of neighbor mobile elements in a particular area. SR beacon represents the sensor involving the information exchange. This scheme addresses the major issue in a sparse WSN regarding energy efficiency and on-time mobile node discovery.

Lifetime maximization and transmission range: In WSN, the unevenly spread communication load causes the energy-hole problem. The corona model relies on adjusting the transmission range of sensors. This concept maximizes the lifetime of the network based on a better sensor deployment pattern (Song *et al*., 2009). Adjustment of the transmission range of sensors increases the network lifetime. In a sparse wireless network, a special mobile entity called MULE, gathers sensor data using their unexpected movement (Shah *et al*., 2003). Whenever a mobile entity moves near a sensor node, it collects information from it. The mobile entity delivers the data when it reaches the corresponding sensor destination.

Optimization techniques: The major issues in designing a WSN include link failures, energy and memory constraints. Many of the WSN design constraints are treated as a multi-dimensional optimization problem. Particle Swarm Optimization (PSO) is an effective and simple optimization algorithm (Kulkarni and Venayagamoorthy, 2011). Multi Objective Genetic Algorithm (MOGA) is a simple framework that defines layout optimization for WSNs (Jourdan and de Weck, 2004). The MOGA designs two different layouts for several sensing ranges. The first layout forms closely packed sensors whereas the second layout consists of the sensors arranged in a hub and spoke fashion.

In distributed Parallel Optimization Protocol (POP), sensors optimize the sensing schedules on their own (Liu and Cao, 2011). The sensor nodes schedule their action such that the same area is not covered redundantly. This increases the global spatial temporal coverage. Virtual Force Directed Co-evolutionary Particle Swarm Optimization (VFCPSO) deploys sensor nodes dynamically to achieve improved coverage. VFCPSO considers the merits from both VF and PSO (Wang *et al*., 2007). VFCPSO repeatedly changes the position of a sensor on the basis of the virtual attractive or repulsive forces from neighboring nodes.

Energy conservation in dense wireless sensor networks: In the dense WSN, energy conservation ensures prolonged network lifetime. A detailed survey in (Anastasi *et al*., 2009) investigates the necessary directions towards energy conservation. Moreover, taxonomy of energy conservation techniques is discussed in detail. This survey mainly concentrates on energy conservation in the sensor network especially if the data acquisition cost is not negligible. This survey introduced “mobility” as a new parameter for energy conservation with the objective of an increasing network lifetime.

A novel node scheduling is a significant scheme for reducing energy consumption as presented by Tian and Georganas (2003). The scheduling scheme aims at maximizing network lifetime by identifying redundant nodes with respect to the coverage area. The nodes assign an on-off mode that result in reduced energy consumption. It also concludes that certain redundant sensing coverage is guaranteed even after the scheduling process. The nodes switch periodically between on-duty mode and off-duty mode using its local information. A node switches to an off-duty mode when it discovers that its neighbor node is in on-duty mode.

A distributed middleware service by Bhattacharya and Abdelzaher (2012) provides a technique with the objective of energy conservation. This focuses on the data placement and caching to preserve battery power. Major traffic in data retrieval, data caching at critical locations, offering those locations for data manipulation decreases the total number of packet transmissions over the network.

SYSTEM MODEL

A sensor network consists of a group of homogeneous nodes. A sensor network is said to be sparse, only if the communication range of a sensor node is compulsorily lesser than twice its sensing range. Each node in the network is outfitted with an elevated antenna. The result of existing proposals regarding connectivity in the sparse WSN to the real environment may be damaged. In reality, the sensor network cannot be too populated because of the spatial reuse problem. If the network is excessively populated, some of the nodes are in active state and some in sleep state. In such a scenario, the average network capacity in terms of density is compromised. Therefore, the proposed approach considers a total area of the sensor deployment regions and describes the final transmission range as the area increases to infinity. This approach considers the square-shaped sensor network with a side of length ‘L’. The node density ‘n’ may either shrink to 0 or to a constant $k>0$, or an increase as the size of the deployment region increases to infinity. Therefore, the proposed criterion is applicable to both sparse and dense WSNs. The sensors in the proposed system discover their neighbors on increasing the transmission range at the rate of double.

Connectivity and transmission range: The connectivity of the network directly relate to the physical environment and the dynamics in the network. In WSNs, most of the network consists of static nodes. Adjusting the transmission range of the sensor nodes at the initial

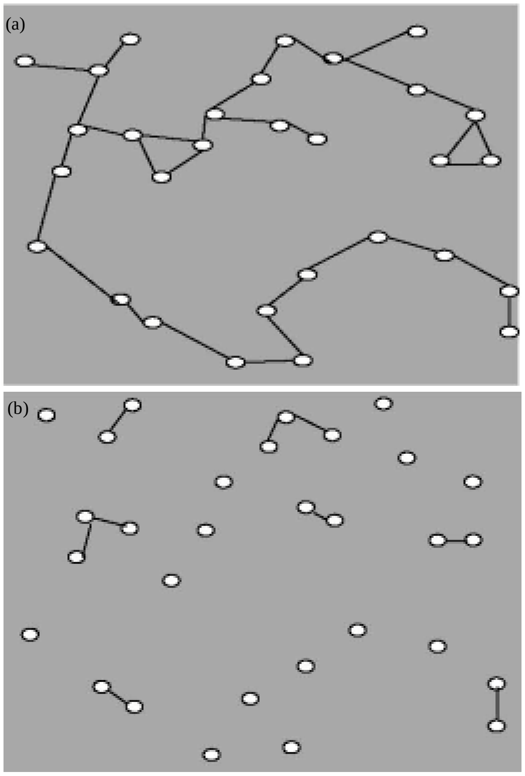

Fig. 1(a-b): Impact of transmission ranges over the network connectivity, (a) Transmission range = 80 m and (b) Transmission range = 40 m

period of the network operation achieves the estimated connectivity. On the other hand, if sensor nodes in the network are dynamic (mobile), the distance between them varies with time. In such a scenario, a continuous adjustment in the transmission range avoids disconnectivity. Figure 1 demonstrates the impact of transmission ranges over the network connectivity. In this scenario, static nodes with the transmission range of 80 m and 40 m are considered. It is clearly explained that, if the transmission range reduced as half, the network almost loses the connectivity.

PROPOSED SOLUTION

This section presents a solution for achieving better connectivity on adjusting the transmission ranges.

Transmission range tuning (TRT): This study presents an effective solution for achieving better connectivity with tunable transmission ranges in WSN. Connectivity loss in the sensor network arises in two scenarios. First scenario is the network with sparsely distributed sensor nodes and in the second, the dense network under partial coverage with a low density of active nodes. The literature proved that, if the communication range is greater than or equal to twice the sensing range, the full coverage ensures that the network has enough connectivity (Wang *et al*., 2003). On the other hand, the number of sensors may not be adequate to maintain full coverage and lifetime simultaneously. Therefore, there is a trade-off between coverage and lifetime that results in partial coverage. There are some scheduling schemes such as partial coverage scheduling and target coverage scheduling algorithms to ensure partial coverage. These scheduling algorithms result in loss of connectivity due to the insufficient number of active nodes. There is no certain condition for achieving connectivity during the partial coverage in WSN. Moreover, it is a difficult task to achieve connectivity in the sparse WSN.

The basic idea of TRT scheme is to tune the transmission range for ensuring better connectivity. This approach ensures on-time data delivery. The sensor node adjusts its transmission range till it finds the neighbor. The sensors in the sparse network are equipped with tall antennas. Each node uses power doubling up a scheme to discover its neighbor. In this scheme, sensor uses mean excess energy at the time of neighbor discovery which doubles the transmitting power till the discovery of the neighbor. This scheme begins with the minimum transmission power and doubles it every time until, a sensor discovers the neighbor. Only at the initial stage of the path discovery, this scheme is used. This process ends, soon after the discovery of a path to the corresponding destination. The sensors then use the maximum transmitting range to broadcast the data. Therefore, it is an energy efficient technique. In general, the increase in a transmission range can be denoted as in Eq. 1:

$$T_{i+1} = 2T_{i,} \qquad i = 0, 1, 2, 3, 4 \ldots n \tag{1}$$

The neighbor discovery process starts with the broadcasting of the beacon (B_Hello) message. The node sends B_Hello message to find the route to the destination. Fields of the B_Hello messages are:

<S_Addr, B_Hello_ID, D_Addr, hop_cnt, curr_txrange>

Where:

S_Addr = Source Address
B_Hello_ID = ID of the beacon message
D_Addr = Destination Address
hop_cnt = Hop Count

curr_txrange = The current transmission range with which the beacon message is transmitted

The fields <S_Addr, B_Hello_ID, curr_txrange> are the unique identities of a beacon message. Since, it is the sparse network, discovering a neighbor node is a tedious issue. If a node cannot find its neighbor by broadcasting B_Hello messages with the current transmission range, it increases the transmission range at the rate of twice the current transmission range. The source node repeats this process till it finds its neighbor. If the neighbor receives the B_Hello message, it sends a reply with the beacon message of reply (B_Rep) only if it has a route to the destination. The source node stores the route in the routing table after receiving the B_Rep message. If it stores at least one route to a destination, it avoids the initialization process. The routing table of a sensor node may contain many routes to the same destination. The neighbor node might have several routes to the destination. However, a node maintains only one route record for that neighbor. The source node forwards the data with the transmission range in which it received the B_Rep message. This approach guarantees high probability of the forwarding success rate.

TRT algorithm: This section provides a brief algorithm explaining the functioning of TRT. Let us define some of the parameters used in the algorithm. S and D denote the Source and Destination sensor nodes, respectively. Let the transmission range (T) with which the source node broadcasts the Beacon hello (B_HELLO) message initially is denoted as 'Ti'. The source node waits for the reply till the end of the Beacon Interval (B_INT). 'SetReply' is a variable that may be set to either True or False. These values indicate if the B_Rep is received or not, for a transmission range T. For certain conditions the power doubling-up scheme increments 'T' as shown in the Eq. 1. If the source node receives a reply for the beacon message, it fixes the range T as the final transmission range. It broadcasts Sensed Information (S_INFO) to the discovered neighbor node.

Algorithm: TRT

```
I=0;
SetReply = False
While (ReplyCount==0)
{
T=Ti;
S broadcasts B_HELLO with Ti
S waits till B_INT
If (SetReply = True)
{
ReplyCount=1;
T=Ti;
End the neighbor discovery process
Broadcasts S_INFO to the discovered neighbor
}
else
I++;
}
```

Exploitation of TRT: The proposed TRT scheme is applicable for both sparse and dense WSN. Analysis conducted in the following sections proves the effectiveness of the proposed system.

Sparse scenario: In a sparse WSN, the distance between two sensors are much greater than their transmission range. TRT in sparse WSN (TRT-S) achieves connectivity between sparsely deployed sensor nodes A and B. Sensor A broadcasts the beacon message with an initial transmission range of Ti. It increases the transmission range using TRT scheme to reach its neighbor. The process continues until it receives a reply for a beacon message. This transmission range adjustment ensures connectivity in the sparse WSN.

Figure 2a and b demonstrate the adjustment of transmission range. Sensor node 'A' transmits a beacon

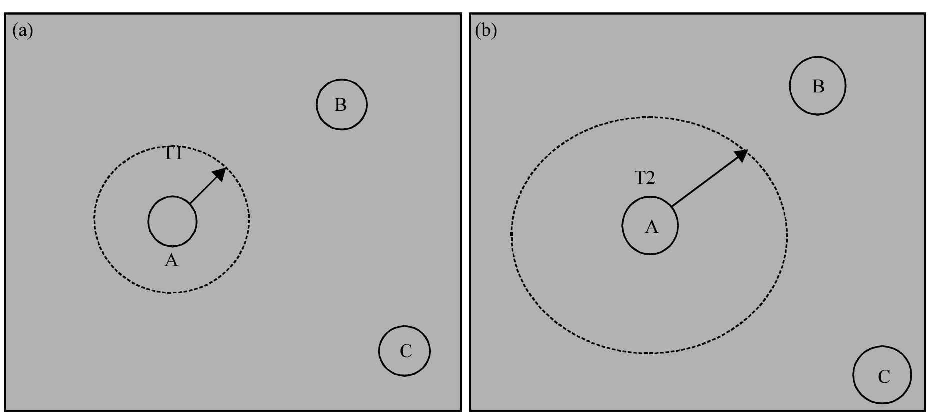

Fig. 2(a-b): (a) Initial transmission range and (b) Transmission range adjustment

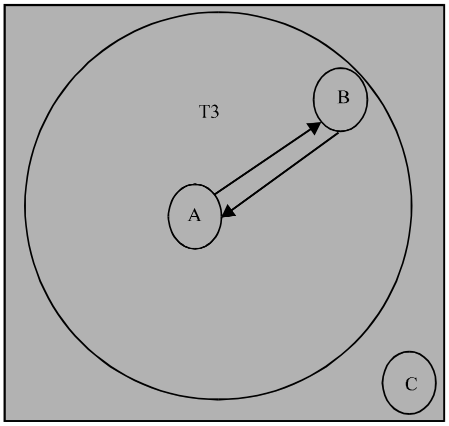

Fig. 3: Transmission range tuning in sparse WSN (TRT-S)

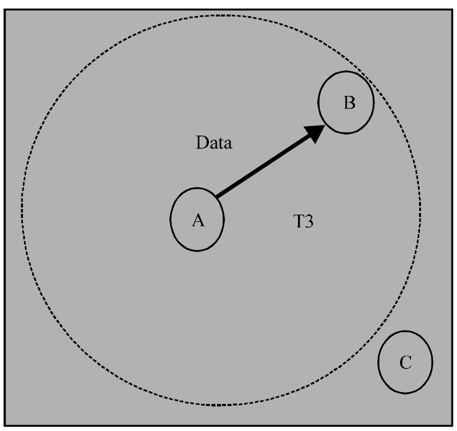

Fig. 4: Data forwarding in sparse WSN (TRT-S)

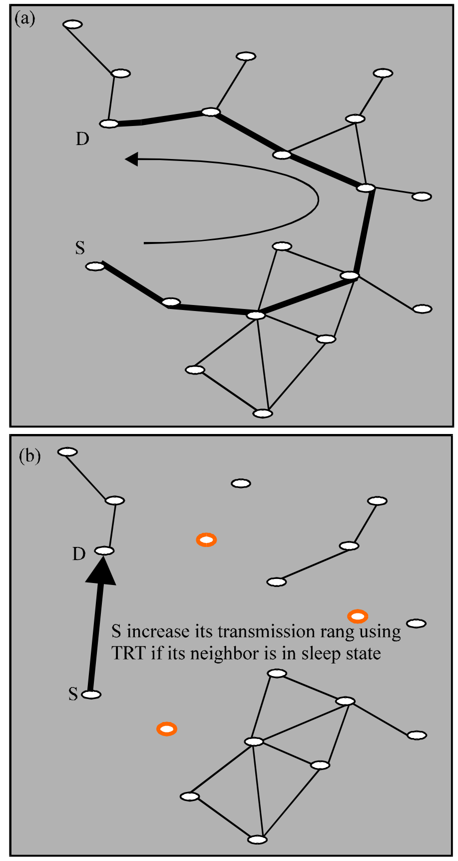

Fig. 5(a-b): Transmission range tuning in dense WSN (TRT-S), (a) High dense active nodes and (b) Low dense active nodes

message with an initial transmission range T1. It doubles the transmission range till it finds its neighbor (T2 = 2T1, T3 = 2T2, T4 = 2T5 and so on). Figure 3 shows, it receives a reply for the beacon message for the transmission range of T3. Node 'A' increases the transmission power in each step till, it finds its neighbor 'B'. Node 'A' sends the data in the transmission range with which it received the B_Rep message as shown in Fig. 4.

Dense scenario: TRT scheme is also applicable for the dense WSN. The scheduling schemes in the dense sensor network reduce the number of active nodes in the network. Most of the nodes switch to sleep mode during the execution of any scheduling algorithms. In that case, the active nodes could not communicate easily as the nodes between them are switched to the sleep mode. Connectivity lacks in that scenario. Therefore, achieving connectivity between active nodes is a difficult task. In this scenario, the source node should increase its transmission power to find its alternative neighbor if its current neighbor is in sleep mode as per scheduling process. Finding the distant alternative neighbor reduces the total number of hops required to reach the destination with reduced average energy consumption. This process is represented as TRT in Dense Wireless Sensor Network (TRT-D). An energy scattering of the nodes is in two modes i.e. active and sleep. The energy dissipation in active mode occurs during transmission and reception. Even, if the node is in idle (sleep) state, it dissipates some amount of non negotiable energy.

Consider the scenario illustrated in Fig. 5. The node S tries to communicate with node D. In Fig. 5a, node S communicate with node D through several hops using its fixed communication range. The nodes in such a network do not adopt any scheduling algorithms. All nodes are active for all the times. In Fig. 5b, the nodes in such a network uses scheduling algorithm for ensuring coverage but not connectivity. Some of the nodes of the current neighbor of the node S enter into sleep mode which motivates the source node to find the alternative node to reach its destination. The node S increases its transmission range using TRT scheme to find the alternative neighbor to achieve connectivity without waiting for the current neighbor to enter into an active state. A source node S obtains a direct connection with the node D which is the alternative neighbor in the network shown in Fig. 5b. This process considerably deduces the number of hops between source and destination. This in turn, reduces the average energy consumption. In this scenario, increasing the transmission range improves the system performance with reduced data delivery latency and it also reduces the overall interference introduced in the system. On the whole, it increases the network life through reduced energy consumption and it achieves on-time data delivery.

Energy analysis for dense network: TRT-D increases the transmission range to achieve connectivity. The transmission range of a node is directly related to the energy consumption. Some of the existing systems achieve energy conservation by reducing the transmission range from the initial range during network operation. Minimizing the transmission range does not mean that it consumes less energy. A simple analysis proves the above statement. The proposed work conserves energy as suggested in (Singh *et al*., 2010).

Energy consumed by the dense network with a large number of active nodes is denoted as E_{HA} and represented in the Eq. 2:

$$EHA = \sum_{j=0}^{n} E_j \tag{2}$$

where, ΣE_j is the total energy consumed by all the nodes between source and destination and n-Number of links between source and destination.

Energy consumed in the dense network having a minimum number of active nodes is denoted as E_{LA} and represented in Eq. 3:

$$E_{LA} = E_{S\text{-}D} \tag{3}$$

where, S-D is the direct link achieved between source and destination using TRT scheme and $E_{S\text{-}D}$- is the total energy consumed by the source node to reach the destination:

$$E_{HA} > E_{LA} \tag{4}$$

The energy consumption is related to the number of hops between source and destination. E_{HA} is higher as it involves several hops to reach destination and hence, consumes a large amount of energy in each step of neighbor discovery. The value of E_{LA} is much less as it involves only few hops to reach the destination on increasing the transmission range. Therefore, energy consumed by increasing the transmission range conserves energy in the dense network. This proves the effectiveness of the TRT scheme.

PERFORMANCE EVALUATION

This section describes the performance evaluation of the TRT scheme applied to both the dense and sparse scenarios. Table 1 lists out the simulation parameters used in the simulation.

Performance evaluation of TRT: This section analyzes the effectiveness of the proposed work in the sparse and dense network.

Performance metrics for sparse scenario: The performance metrics used to simulate the proposed work for the sparse scenario is discussed in this section.

Discovery miss ratio: Discovery Miss Ratio is a fraction of the beacon packets that do not discover the neighbor.

Average data delivery latency: Average data delivery latency is the time taken by the sensor to transfer a set of data to sink in a single path discovery. It is a function of the number of data delivered in a single path discovery.

Mean energy consumption: Mean Energy Consumption is the mean energy level used up by the sensor to transfer each data to the sink successfully.

Performance analysis of TRT in sparse scenario: This section evaluates the performance of the proposed work in the sparse scenario (TRT-S). The simulation results

Table 1: Simulation parameters of the TRT evaluation

Parameter	Values
No. of nodes in sparse scenario	20
No. of nodes in dense scenario	100
Simulation area (m)	1000×1000
Beacon size (bytes)	30
Beacon generation interval (ms)	15
Simulation time (sec)	600
Antenna type	Omni directional
Software for simulation	Network simulator 2
Packet size (bytes)	1024
Network interface type	Wireless physical
Queue type	Drop tail
Propagation model	Two ray ground
MAC type	Mac/802.11

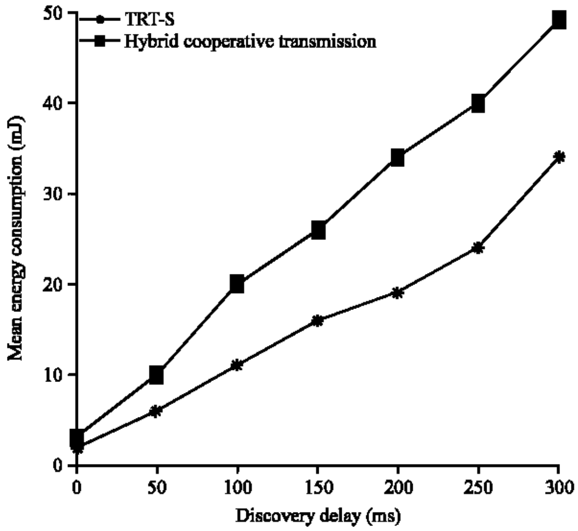

Fig. 6: Mean energy consumption of TRT-S

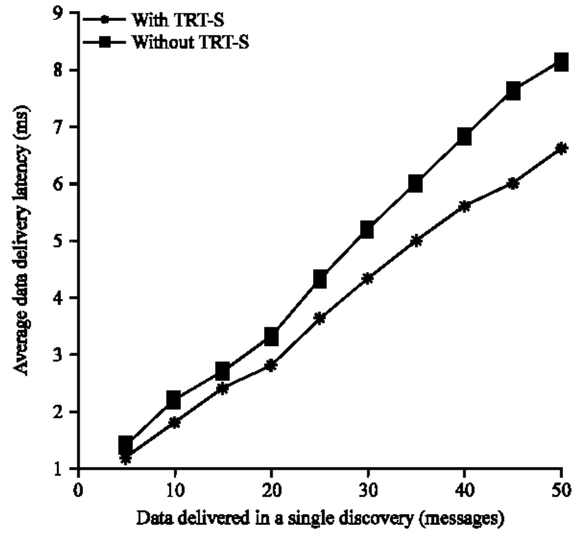

Fig. 7: Average data delivery latency of TRT-S

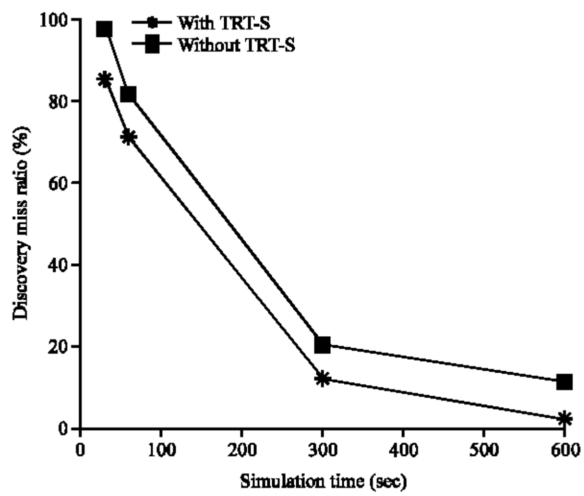

Fig. 8: Discovery miss ratio of TRT-S

prove that the proposed work outperforms existing solutions. The proposed work achieves better connectivity and saves energy in an effective manner.

Mean energy consumption: Reducing energy consumption is one of the major focuses of this study. The TRT-S scheme consumes less energy compared to the hybrid cooperative transmission scheme. Figure 6 demonstrates Mean Energy Consumption of the proposed scheme. In the hybrid cooperative transmission scheme, it uses multi-hop communication and cooperative transmission wherever necessary. As estimated, energy consumption increases with discovery delay. However, even for smaller discovery delay, the energy reduction by hybrid cooperative transmission is more compared to TRT-S. TRT-S reduces energy consumption resulting in enhanced network performances.

Average data delivery latency: Figure 7 demonstrates the average data delivery latency that increases with the number of data delivered in a single path discovery. The average data delivery latency is less in the approach that uses TRT-S scheme. It ensures on-time data delivery by discovering neighbors on increasing the transmission range. The latency of the data delivery increases with the amount of data delivered.

Discovery miss ratio: The discovery miss ratio decreases with an increase in simulation time as shown in Fig. 8. It is impossible to discover a node within a very short period of time in a sparse WSN. Therefore, the discovery miss ratio is higher in initial simulation time periods. But, as time expands, the discovery miss ratio decreases as it discovers possible neighbors. TRT-S scheme achieves the reduced discovery miss ratio.

Performance metrics for TRT-D Scenario

Throughput: Throughput is defined as the average number of data packets that ensures on time data delivery to the destination.

Lifetime enhancement ratio: Ratio of increment in the network lifetime to the estimated lifetime of the network.

E_SAVE factor: This parameter evaluates TRT-D's ability to save energy. A huge amount of energy is saved if the

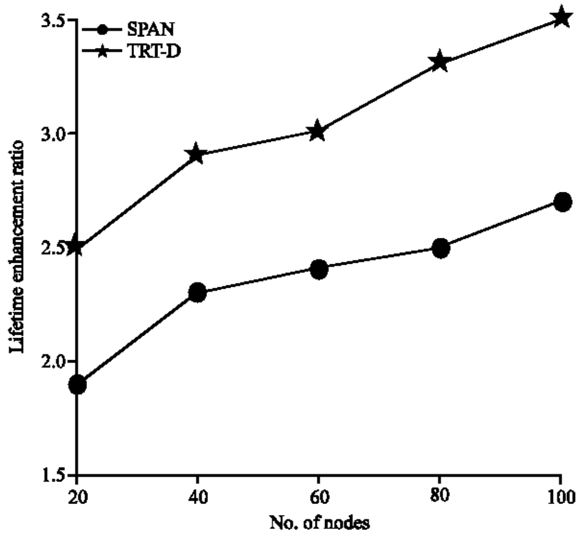

Fig. 9: Lifetime enhancement ratio of TRT-D

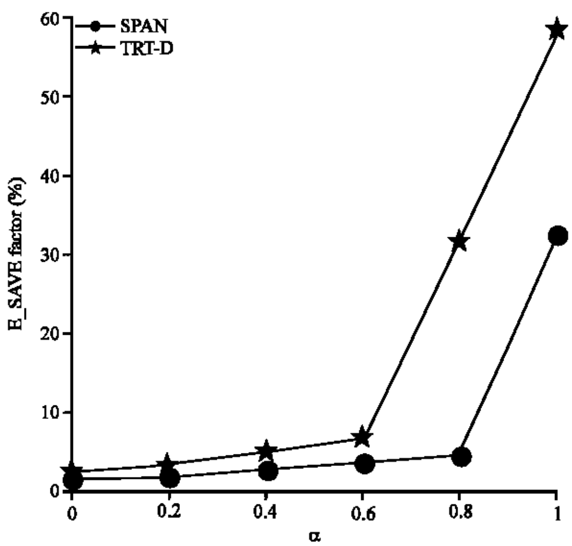

Fig. 10: E_SAVE factor of TRT-D

source node reaches the destination on increasing the transmission range with less number of hops. The ratio of nodes switches from sleep mode to active mode is denoted as ‘α’.

Performance analysis of TRT-D scenario

Lifetime enhancement ratio: Figure 9 shows the relationship between the number of nodes and lifetime enhancement ratio. Energy consumption using the proposed work achieves the increment in network lifetime. TRT-D ensures increase the lifetime enhancement ratio to the network provides a large number of active nodes. The

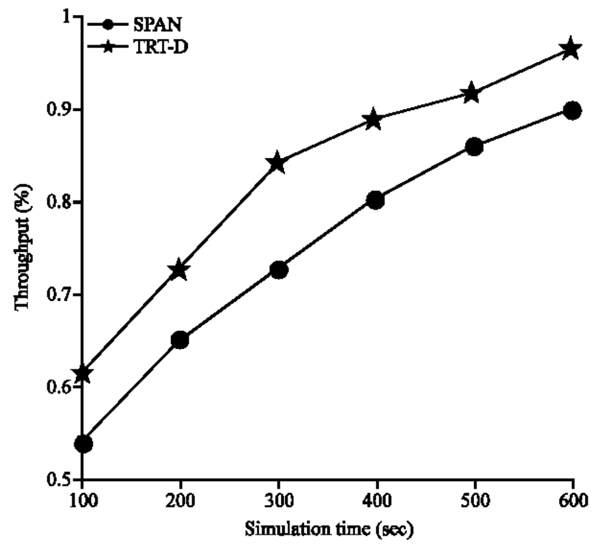

Fig. 11: Throughput of TRT-D

performance of TRT-D is compared with SPAN protocol. TRT-D performs better than the SPAN (Chen *et al*., 2001).

E_SAVE factor: Figure 10 explains that the proposed work TRT-D saves a considerable amount of energy over its implementation in the dense sensor network compared to SPAN protocol. The amount of energy saved increases as the value of ‘α’ increases. Increment in ‘α’ denotes the availability of higher number of active nodes to achieve direct connectivity on increasing transmission range in the dense network. Since the connectivity is the main objective of the proposed work increment in number of active nodes facilitates increment in the E_SAVE Factor.

Throughput: Figure 11 demonstrates that the proposed TRT-D achieves better throughput compared to SPAN. As the simulation time runs out, connectivity with neighbors increase using TRT-D scheme. Therefore, data from the source node reaches the destination as soon as possible leads to the increment in throughput. Experiment result shows that TRT-D scheme results in increased throughput in percentage compared to the SPAN protocol.

CONCLUSION

This study proposed an approach for achieving connectivity in a sparse WSN without reducing or affecting the coverage range, called TRT. The proposed TRT approach achieves connectivity by tuning the transmission range of a node to find its neighbor. The tuning of the transmission range continues till a node finds its neighbor. The source node broadcasts a beacon message to discover its neighbor node. If the neighbor node has the route to the destination, it does a reply to the beacon message. The proposed TRT scheme ensures connectivity in both the sparse and dense WSN and represented as TRT-S and TRT-D, respectively. TRT-D also ensures energy conservation. The proposed work attains maximum connectivity without having great impact on coverage and network lifetime. The simulation shows effectiveness of the proposed work and outperforms the existing systems.

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