

An Efficient Approach to Reduce the Energy Consumption in Wireless Sensor Networks through Active Nodes Optimization

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Abstract

A sensor network is made up of numerous small independent sensor nodes with sensing, processing and communicating capabilities. The sensor nodes have limited battery and a minimal amount of on-board computing power. This paper presents a novel methodology that utilizes source and path redundancy technique to effectively reduce the required energy consumption while at the same time maximize the lifetime of the sensor networks. In addition, the proposed methodology presents a strategy to optimize the number of active sensor nodes and assign equal time slots to each sensor nodes for sensing and communicating with the Base Station (BS). Simulation results demonstrate that the proposed methodology significantly minimizes the energy consumption and consequently increases the life time of the sensor nodes.

Keywords: Base station, energy consumption, sensor node.

I. Introduction

A wireless sensor network (WSN) is made of numerous small independent sensor nodes to monitor environment at different locations. The sensor nodes, typically the size of 35mm film canister, are self-contained units consisting of a battery, radio, sensors, and a minimal amount of on-board computing power. Nodes must have self configuration and adaptation mechanisms to support fault tolerance. In the past few years, the rapid development in miniaturization, low power wireless communication, micro-sensor and small-scale energy supplies have given WSNs a new technological vision. WSNs show great potential for increasing the information available to people in a wide variety of consumer and industrial applications (e.g., smart buildings, position sensing, target tracking, interactive museums, managing inventory control, and home-automation). While a lot of research has been done on some important aspects of WSNs such as architecture and protocol design, energy conservation, and localization, supporting Quality of Service (QoS) in WSNs is still a largely unexplored research field. This is mainly because WSNs are very different from traditional networks.

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Communicating one bit over a wireless medium at short ranges consumes more energy than processing that bit. With the current technology, the energy consumption for communication is several magnitudes higher than the energy required for computation; and wireless communication is foreseen to continue to dominate energy consumption in the near future. There are two possible ways to decrease the energy used for communication in a sensor network: minimize the amount of the transmitted data or decrease the communication range. The transmission energy is proportional to d^α , where d represents the transmission distance and α represents the attenuation exponent. Therefore, minimizing the amount and the range of communication can significantly prolong the life of a sensor network.

In this paper, we propose a novel methodology that utilizes the source and path redundancy technique to effectively reduce the required energy consumption while at the same time maximize the lifetime of the sensor networks. In [2], the concept of moving the BS to its optimum position was introduced. In addition to position optimization, the proposed algorithm optimizes the number of active sensor nodes with respect to the location of the BS. Simulation results demonstrate that the proposed approach significantly reduces the energy consumption while at the same time provide a simple and efficient architecture for sensing active nodes.

Current interest of WSNs includes optimizing the performance of sensor networks for distributed sensing applications [3]. It is well known that QoS is an overused term with various meanings and perspectives. Different technical communities may perceive and interpret QoS in different ways. In general, QoS is mainly concerned with the satisfaction of the users and measures the service requirements that must be met when transporting a packet stream from the source to the destination. In this scenario, this refers to an assurance by the internet to provide a set of measurable services attributed to the end-to-end users in terms of jitter, available bandwidth, and packet loss. In general, accuracy, precision, energy/power, lifetime, cost, etc. has to be taken care of by the network in order to provide better QoS. From the network perspective, the goal is to provide QoS services while maximize the network resource utilization. In order to achieve this goal, the network is required to analyze the application requirements and deploy various network mechanisms.

The sensor networks can be categorized by the periodicity of data transmission. In a time-driven network, every node sends messages periodically, while in an event-driven, a node sends message only when sensing a phenomenon. The third category is the query-driven approach when the sensors transmit data only after receiving a query from the BS. In query-based sensor systems, a user may issue a query with QoS requirements in terms of reliability and timeline and expect a response to be returned within the deadline. This paper investigates the problem of optimizing sensor network that has sensor nodes whose active lifetime is significantly shorter than the required lifetime of the sensor network. In order to satisfy these QoS requirements, we use the fault tolerance mechanisms through source and path redundancy technique which may cause the energy of the system to be quickly depleted. We show that the utilization of *source* and *path* redundancy technique can effectively reduce the required energy consumption while at the same time maximize the lifetime of the sensor nodes.

The rest of the paper is organized as follows: Section II provides the state of the art research that has done in this area. Section III presents a discussion on the proposed approach for optimizing the number of active sensor nodes. Section IV presents the simulation results that demonstrate the success of the proposed approach. Finally, we conclude the paper in Section V.

II. Related Work

WSNs usually contains thousands or millions of sensors, which are randomly and densely deployed (typically 10 to 20 sensors per m^2) [1]. Due to high number of node count, it is not only impossible to keep track of each node but also not feasible to replace each node in case of their failure. Therefore, the number of nodes more than the necessary amount to cover the area is deployed to cope with the failure problem. This problem of WSNs is referred as redundancy [1]. This arouses the need for the sensor nodes with greater active lifetime to prevent the failure problem. The main goal is to prolong the lifetime of the network, which can be defined in several ways: (1) the time when the first node depletes its battery, (2) the time till a given percentage of the sensors have enough energy to operate, and (3) the time till a given percentage of the region is covered by active sensors [2].

Recently, much research has done in the area of energy saving issues in WSN's. Many proposals are put forward to minimize energy consumption in sensor networks [2, 4, 5]. Various power saving schemes have been proposed not only for the hardware and architectural design but also for designing the algorithms and protocols at various layers in the network architecture.

In [2], a theory is proposed to save the energy by reducing the range of communication and the amount of data transmitted where as in [6] a model is proposed in which the sensor nodes are forwarded to sleep mode whenever the nodes are not sensing the environment. In addition, each location of the physical environment is kept under the examination with a set of sensor nodes (with different sensing periods allotted) and rest of the sensor nodes go to the sleep mode. In [4], a particular location in the environment is sensed by only one sensor node at a time. But as a single sensor node is prone to failure, there may be errors in the sensing. In addition, a query-based optimal path and source redundancy approach is proposes in [7]. In order to achieve the QoS and maximize the lifetime of WSNs, the approach finds an optimal path by utilizing the source redundancy technique.

The majority of work till now considered sensor networks to be entirely immobile. In [2], a new concept of moving the BS to a position at which the distance between the active sensor nodes and BS becomes optimum has been introduced. This paper proposes a novel approach in which the BS is kept mobile where as a large majority of the sensor nodes are forwarded to sleep mode by optimizing the number of active sensor nodes. However, for distance optimization, this paper uses the proposed approach of [2].

III. The Proposed Method for Active Sensor Node Optimization

Before introducing the proposed algorithm, it is worth mentioning some of our key assumptions. We assume that each node is aware of its location and it is static in nature. The BS, on the other hand, is unaware of its location and can be moved unlike the nodes. In addition to that, the sensing area of the nodes is assumed to be a circle of radius r with the center of the circle as the node itself. Finally, we assume that all the nodes are synchronized with their neighboring nodes and can communicate with each other. The first step of the proposed method is the calculation of the optimal distance for placing the BS to its optimum position. We consider that the BS moves relatively fast to the respective optimal location once the minimum distance is determined. After

successfully computing the optimal distance, the next step is to use the proposed method that reduces the number of active nodes to communicate with the BS.

A. Strategy for Moving the Mobile BS

In order to move the BS to the optimum position we consider the same theory as proposed by [2]. With respect to the proposed strategy, the BS is placed to its optimum position by determining the distances between all the sensor nodes with BS.

B. The Proposed Method for Optimizing the Number of Active Nodes

The lifetime of a sensor network has two phases: first is the initializing phase and the second is the sensing phase. In the first phase, the sensor senses their own position and synchronizes themselves with the neighboring sensors [6]. After the initialization phase, the sensor nodes are ready to sense the physical environment. The proposed method introduces the strategy for reducing the number of active nodes which sense the area and communicate with the BS. The proposed methodology can be understood by Figure 1. As soon as the BS takes its optimum position, only those sensor nodes which are within the range of $2r$ from the BS remain active. In Figure 1, the BS is shown in middle of a grid and surrounded by the sensor nodes.

In Figure 1, only the sensor nodes which are within the range of $2r$ (Nodes are named as follows *A, B, C, D, E, F* and *G*) from the BS communicate with the BS where as the rest of the nodes go to the sleep mode. When one particular sensor node goes to sleep mode, its sensing, communication and computation components can all be asleep and only a timer needs to work and wake up all components according to its predefined schedule. The BS has the knowledge of the coordinates of sensor nodes which are within the range of $2r$ in its memory. The placement of the BS to the optimum position reduces the distance between the active nodes and the BS which consequently minimizes the communication distance between them. Thus, the proposed methodology provides these reductions in both the distance and the communication cost that become one of the reasons for giving better energy consumption. In other words, the proposed methodology minimizes the number of active nodes that reduces the total energy consumption which is currently one of the QoS requirements in WSNs.

The next step of the proposed methodology is the division of the sensing period of the remaining active nodes. Previous work has the concept of keeping only one sensor node to be active for

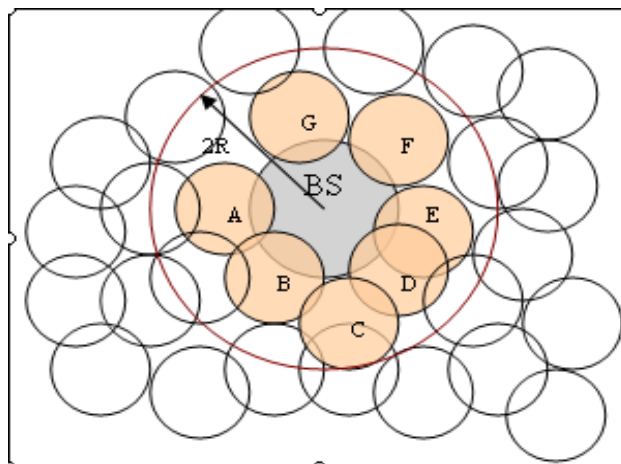


Figure 1. Active nodes within the range of $2r$ of BS

sensing a particular region in the environment and so only one node consumes energy and hence the energy is saved [4, 8]. However, one of the common problems with single node activation is that it is prone to failure very often which may introduce errors or false alarms. In order to overcome this problem, our proposed methodology uses the concept of a location which is sensed by more than one node alternately for regular intervals of time. According to our model, the sensing is always done by the active nodes. The active node sensing occurs in the form of cycles of predetermine equal time of T_{total} . Each cycle (T_{total}) is divided into number of time slots T_{slots} with respect to the number of active nodes. This division provides the required time to perform sensing for one active node. This scenario is shown in figure 2. The value of T_{slots} depends on the number of optimized active sensor nodes N . This relationship can be expressed as: $T_{slot} = T_{total} / N$.

To understand this concept, let us assume that one cycle (T_{total}) of the sensing period is of 70 minutes. For our numerical calculation, we kept N to be 7 active nodes which come under 2r range from the BS. The use of 7 active nodes implies that we need to divide this sensing period among the 7 sensing nodes which are named as: A, B, C, D, E, F, and G as shown in Figure 3. Taking this scenario into account, each node has to sense for 10 minutes alternately in one cycle of sensing period. The orders of the sensing for the nodes are decided by distance from the BS which is calculated by the proposed methodology. The node which is nearest senses first and so on. Consequently, each point in the target environment is covered by at least one working active node that communicating with the BS. Hence 100% sensing coverage is achieved where as the average lifetime of each sensor nodes is increased as the sensing period gets divided among the active nodes. This shows that the required energy consumption is reduced by the proposed methodology and achieved the desired QoS requirement for the WSNs.

IV. Performance Analysis of the Proposed Algorithm

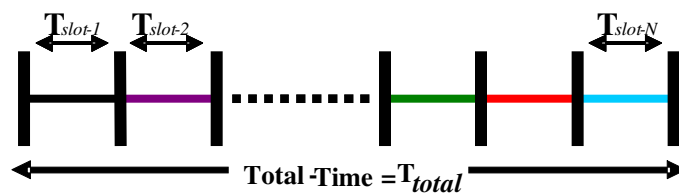


Figure 2. Sensing period of the Active nodes

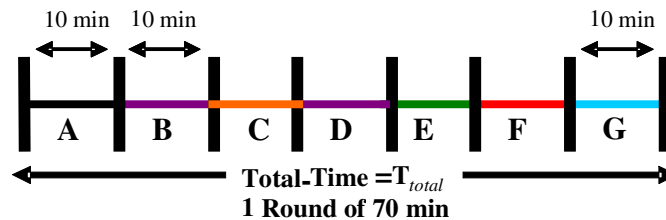


Figure 3. Sensing period for 7 Active nodes

The proposed methodology is modeled and implemented in C language. For the sake of simulation, we assume that the network is divided into small clusters with typically 450 to 500 nodes within the coverage area of a BS. The algorithm calculates the individual distances from the various nodes and the corresponding BS. After calculating the minimum energy utilized by the nodes, it places the BS to the optimum position. Furthermore, the algorithm determines which are nodes are within the range of the BS. Sensor nodes that found within the $2r$ radius of the BS will be kept active whereas all the sensor nodes that are out of range force to move in the passive state. We assume the value of α to be 2. Note that the value of α may vary typically from 2 to 5. The proposed model can be explained by the flow graph as shown in figure 4. The

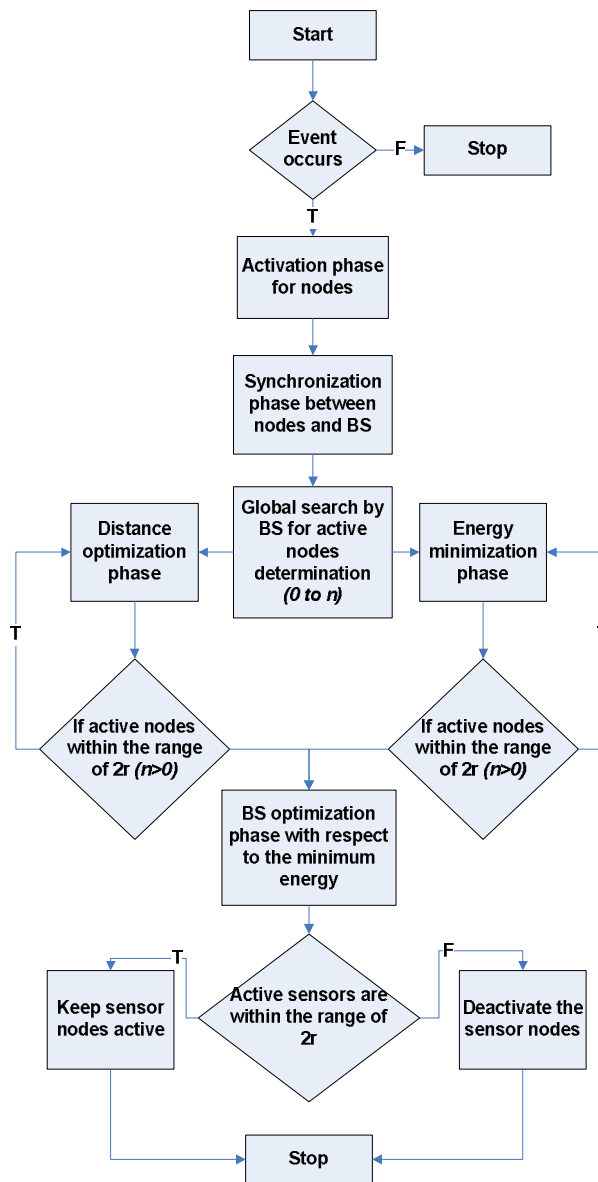


Figure 4. Flow graph for the proposed model

proposed algorithm starts working with the occurrence of any event in the environment. Initially, all sensor nodes become active and they synchronize themselves with the BS. The algorithm starts calculating distance between n sensor nodes (where n indicates the number of nodes) and the BS until it records minimum energy required to communicate with the BS. It should be noted that the energy consumption is a function of distance between the communicating BS and the sensor nodes. The algorithm intelligently places the BS to the optimum position where the minimum energy is consumed by the network. Furthermore, the algorithm checks the position of each sensor node for decision making. If the targeted nodes are not within the range of $2r$ from the BS, they are forwarded to sleep mode. As a result, only those sensor nodes are kept active which are within the range of $2r$ from the BS.

For the sake of performance analysis of the proposed algorithm, we consider a cluster of network of 500 nodes with the radius of the BS is assumed to be 35 mm. The energy required to transmit one unit of data is assumed to be 2.5 KJ. The total energy of a node is assumed to be 300 KJ. Note that the node dies as soon as all its energy is consumed. Figure 5 shows the comparison of the energy consumption for a network having a static BS with the network having a mobile BS. It can be seen in figure 5 that the entire network consumes 3.5×10^7 KJ of energy with 100 active nodes when the BS is in the passive state. On the other hand, the total energy consumption is reduced to 1.4×10^7 KJ when the BS is moved to the optimum position. In order to verify the consistency of the simulation results, we run the simulation for 1000 active nodes instead of 500 active nodes with the radius of 50mm. Figure 6 explains this scenario. This can be seen in Figure that the energy consumed by the entire network with 200 active nodes is 7.5×10^7 KJ when the BS is static. On the other hand, this energy reduces to 5.21×10^7 KJ after moving the BS to its optimum position. One can, therefore, conclude that the energy consumption is reduced by more than 45% through our proposed algorithm compared to other well known methods.

It should be noted that as the number of active nodes increases, the difference between the energy consumption for both the static and the mobile BS increases significantly which can be clearly evident in figure 5 and 6, respectively.

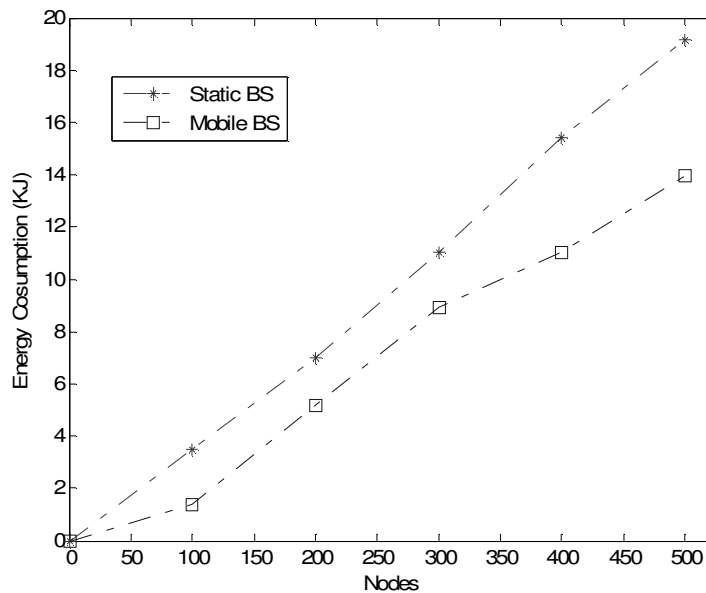


Figure 5. Nodes vs. energy with no. of active-nodes = 500 and BS-radius = 35 mm

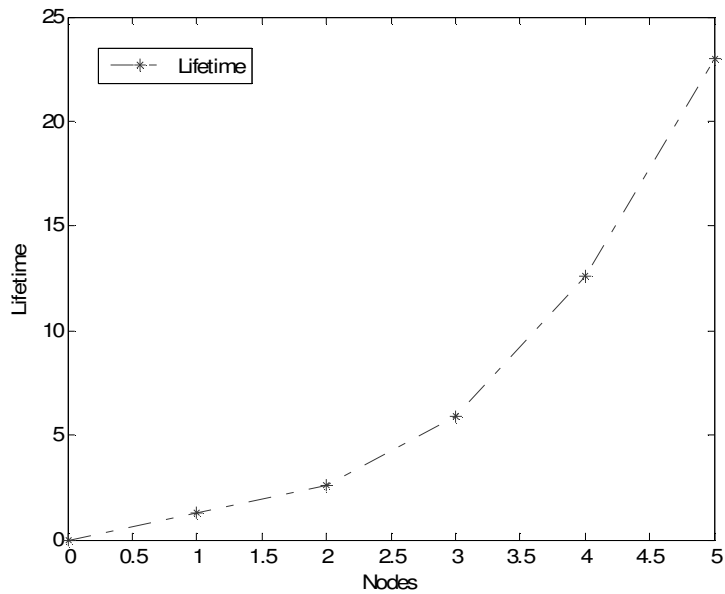


Figure 6. Nodes vs. life time with no. of active-nodes = 5 and BS-radius = 35 mm

Figures 7 and 8 demonstrate the simulation results of the lifetime of a particular node when there is more than one active node exist. According to the proposed methodology, we divide the sensing period among the optimized active nodes. By dividing the sensing period among the nodes, the sensing time of one particular node is reduced significantly. This ensures that the energy required by a particular node to communicate with the BS is reduced and consequently increases the lifetime of a sensor node. Also, by dividing the sensing period among the optimized active nodes assures that each location in the environment is sensed by at least one active node. This ensures 100% coverage of the environment.

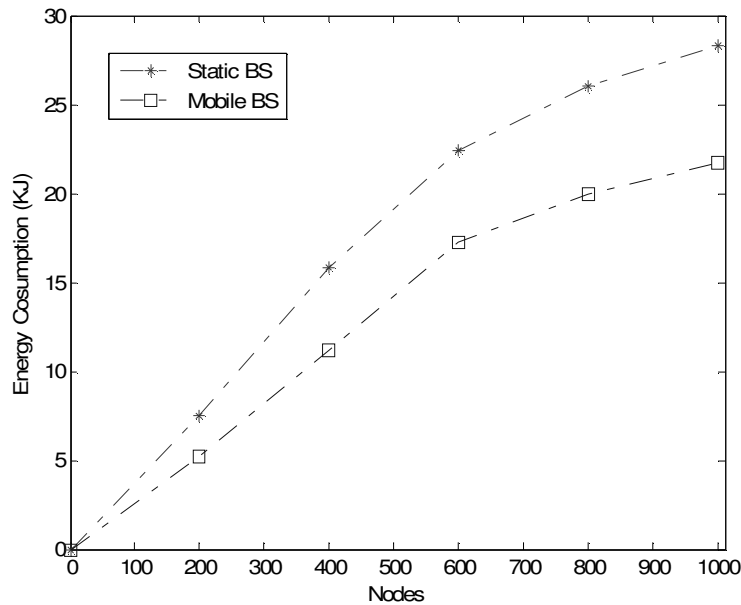


Figure 7. Nodes vs. energy with no. of active-nodes = 1000 and BS-radius = 50 mm

Figure 7 shows the lifetime of a sensor node where the radius of the BS is assumed to be 35mm. On the other hand, figure 8 shows the lifetime of the sensor node with the radius of the BS of 50mm. It is observed that in figure 7, the lifetime of one node is 2.6 when the sensing period is divided among 2 active nodes in the network with 35mm radius of BS. The lifetime increases from 2.6 to 2.75 in figure 8 for the same parameters when the radius of BS is increased by 50mm. This is because as the radius of BS increases, the sensor node has to communicate for a shorter distance because the effective distance between the sensor node and the BS decreases. It can be verified that as the number of active nodes increases, the time allocated to one active node for sensing and communicating decreases and hence the lifetime of that node increases. Thus, this implies that our proposed model not only reduces the overall energy consumption of the network but also increases the lifetime of the nodes significantly.

V. Conclusion

In this paper, we introduced the concept of optimizing the number of active sensor nodes after placing the BS to optimum position. Once the optimum position of the BS is determined, we optimize the number of the active nodes. The simulation results of the proposed algorithm demonstrate that the energy consumption of the network is reduced by a very large factor. In addition, our experimental verifications show that the proposed algorithm provides much longer network life through energy conservation and balancing among sensor nodes. Finally, the simulation results show that the proposed algorithm gives comparatively a small communication overhead required to establish a working duty schedule among nodes.

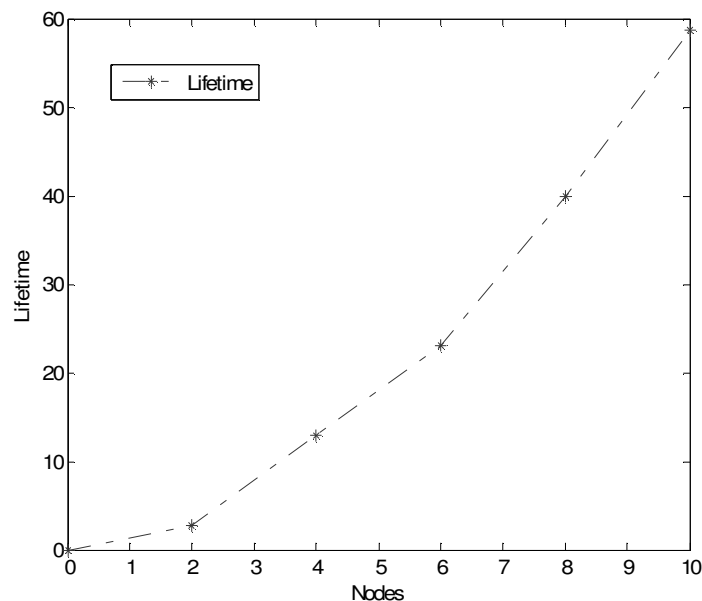


Figure 8. Nodes vs. life time with no. of active-nodes = 10 and BS-radius = 50 mm

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