Analysis of Lifetime of Wireless Sensor Network

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Abstract

The advancement in last decade in electronics & communication, computer science and information technology domain has resulted in the new computing and communication era, known as Wireless Sensor Networks. The routing protocols differ on the basis of application and network architecture. With awareness is a compulsory design criterion, many new protocols have been specifically designed for routing, power management and data dissemination. Efficient routing in a sensor network requires that routing protocol must minimize network energy dissipation and maximize network lifetime. This paper analyses the lifetime of different routing protocols for wireless sensor networks.

Keywords: *Sensor networks, virtual coordinates ad hoc routing*

1. Introduction

Wireless sensor network (WSN) consists of a large number of sensor nodes. A sensor node is defined as a small, wireless device, capable of responding to one or several stimuli, processing the data and transmitting the information over a short distance using radio frequencies or laser approaches [1]. The sensor actually senses the physical phenomenon close to the point of their occurrence and then transforms these measurements into signals that can be processed to reveal some characteristics about phenomena located in the area around these sensors. The types of phenomenon that can be sensed include acoustics, light, humidity, temperature, imaging, seismic activity, any physical phenomenon that will cause a transducer to respond. Sensor node consists of sensors, processor, memory, communication system, mobilizer, position finding system, and power units. WSN collects data from target area and then forwards towards an infrastructure processing node or base station (BS.) A BS and/or sensor nodes may be a fixed or mobile. WSNs may consist of up to thousands of nodes, which can be deployed in very high density, in homes, highways, buildings, cities, and infrastructures for monitoring and/or controlling purposes. Figure 1 reproduces a schematic diagram of sensor node components and WSN [2].

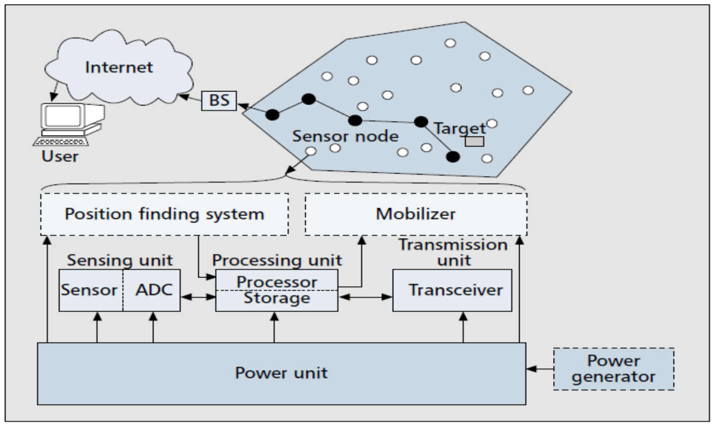

Figure 1. The components of a sensor node and WSN [2]

Routing is a process of determining a path from a source node to its destination for data transmission. Routing in WSN is very challenging due to the resource constraint characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks. In WSN, the routing protocols [3, 4] are application specific, data centric, capable of aggregating data and capable of optimizing energy consumption. The important characteristics of a good routing protocol for WSN are simplicity, energy awareness, adaptability and scalability due to limited energy supply, limited computation power, limited memory and limited bandwidth of WSN [5, 6, 7]. The main design goal of WSNs is to carry out data communication while trying to prolong the lifetime of the network. The design of routing protocol in WSNs is influenced by many challenging factors as summarized below:

Node deployment: Node deployment in WSN can be either static or dynamic as per requirement of applications. Node deployment affects the design of the protocol of routing, clustering, node life, energy conservation in WSN, *etc.*

Network dynamics: Dynamic nature of BS or sensor node has greater effects on coverage and connectivity of WSN. As connectivity among sensor nodes change, stability and route finding becomes one of the challenging issues. This problem becomes more complex in the case of mobility of both BS and sensor nodes.

Energy conservation: During the creation of an infrastructure, the process of setting up the routes is greatly influenced by energy considerations [8, 9, 10]. In many cases, multi-hop communication conserves energy of sensor nodes compared to one hop communication and hence resulting in life prolongment. But this creates another kind of serious problem like quick power drainage of forwarding nodes as compared to nodes at last layer in multi hop communication, hierarchical communication. On the other hand, significant overhead due to network management and medium access control occurs in multi-hop routing.

Fault tolerance: Network need to work even when some of the sensor nodes fail. This is related to design of MAC and routing protocols.

Scalability: Many sensor nodes may not be working due to power drainage, physical damage etc. This creates holes in the existing WSN. Some times this breaks the network into two or more partitions. In such scenario, adding extra sensor nodes are requirement. Design of WSN must support scalability.

Hardware constraint: With low energy, low computational capacity, low communication range, it becomes one of the important design issues related to power saving, quality of service etc. MAC layer may be designed in to synchronize the wake and sleep time with application requirement [11].

Sensor network topology: It must be maintained even with very high node density. Maintaining the topology in the mobile scenario becomes one of the important and necessary issues.

Environment: Sensor nodes should be functional even in non-conducive/hostile environment.

Transmission media: Generally, radio frequency or infrared wireless communication is used in WSN. Both have well known characteristics and associated problem like fading, multi-path propagation, reflection, refraction, inter symbol problem, high error rate etc. These affect the operation of WSNs.

Data delivery models: Data delivery may be categorized in to following: event driven, query-driven, reactive, proactive, hybrid. Choosing one data delivery model is basically requirement of the application of the WSNs.

Node capabilities: Depending on the application, a node can be dedicated to a particular special function such as relaying, sensing and aggregation since engaging the three functionalities at the same time on a node may quickly drain the energy of that node.

Data aggregation/fusion: It is fact that more battery power is consumed during communication. So, data aggregation/fusion helps in reducing number of communications by using some aggregate functions like suppression (eliminating duplicates), min, max and average.

Charging and recharging battery of sensor nodes becomes quite difficult especially in hostile environment. Even though, it is possible to replace the battery, it will interrupt the continuous operation of WSNs. This may lose some of the packets. Losing some of the packets is not good for the application where continuous surveillance is needed. All systems, processes and communication protocols for sensors and sensor networks must minimize power consumption. For aggregating data collected from sensor nodes in different locations, time synchronization and node localization during WSN initialization, effective internode communication is required. The radio energy consumption is of the same order in the reception, transmission, and idle states, while the power consumption drops to at least one order of magnitude in the sleep state [12]. Hence, the radio is put to sleep whenever possible and used sparingly. The power consumption of on-board sensors must be reduced, depending upon the specific application. Each sensor node in WSN coordinates with its neighbor nodes in forwarding their packets towards destination. Thus, the main design goal of WSN is to carry out data communication while trying to prolong the lifetime of the network.

The limited power of sensor nodes requires an energy-aware communication involving WSN and hence a design of energy-efficient communication protocol [13]. In order to effectively use the limited energy available, computation costs which are much smaller than the communication cost, is utilized to minimize the amount of information that actually has to be sent [14, 15]. From [16, 17], one can observe that communication cost is an important factor. The communication cost can be reduced significantly by using cluster based communication as compared to one without clustering. Clustering allows the scarce resources such as frequency spectrum, bandwidth and power to be used efficiently. The clustering protocol divides the WSN into virtual groups called clusters. Each group has a cluster head and one or more member nodes. This supports in-network aggregation which is used to aggregate information from various sensors and to summarize that information before communicating and passing it on to the other nodes. This increases the life span of WSNs. The clustering protocols have other advantages like scalable, energy efficient in finding routes and easy to manage.

This paper analyses seven existing routing protocols of WSN. The comparison takes into consideration the network lifetime of WSNs. The rest of this paper is organized in following sections: in Section 2 presents related work. Section 3 analyses the routing protocols. Section 4 uses OMNET++ for simulation and shows the simulation results for the protocols analyzed. Finally, Section 5 concludes the paper.

2. Related Work

Well-known wireless routing protocols such as AODV [18] and DSR [19] are not appropriate solutions for sensor networks as they do not scale well for large networks and have relatively high overhead. Routing protocols that use geographic location like Greedy Perimeter Stateless Routing (GPSR) [20] and Geographic Routing Without Location Information (GRWLI) [21] can scale well. Unfortunately, obtaining the location is not only costly and susceptible to localization errors, but sometimes even not feasible. Thus, greedy forwarding cannot guarantee reachability of all destinations because of possible dead ends [22]. Transformation of geographic coordinates can be considered as a first step toward the use of virtual coordinates only [23]. Also, hierarchical approaches using a mixture of geographical coordinates and a virtual overlay have been considered [24]. Comprehensive surveys of such virtual coordinate-based solutions can be found in [25, 26].

Virtual coordinate system (VCS) based routing protocols have been proposed to overcome these limitations. In such protocols, routing is performed in a greedy manner based on virtual (or logical) coordinates obtained through a virtual coordinate establishment mechanism integrated with the routing protocol or through an external virtual coordinate system. VCS based routing protocols require only local interactions and minimal state information that does not grow with the size of the network. As a result, such protocols have increased scalability and reduced overhead.

3. Analysis of Existing Routing Protocols in WSNs

This section presents the related work of seven existing routing protocols for WSN.

3.1. Multihop-LEACH

Multihop-Leach [27] is a cluster based routing algorithm. There are two models in Multihop-LEACH protocol. Multi-hoping is applied to both inter cluster and intra cluster communication. In *Multihop inter cluster operation* model network is grouped into different clusters. The respective cluster head gets the sensed data from its cluster member nodes, aggregates the sensed information and then sends it to the Base Station through an optimal multihop tree formed between cluster heads (CHs), with base station as root node. In *Multihop intra cluster operation a* single hop communication is used within a cluster for communication between the sensor nodes. The cluster head nodes are rotated randomly and periodically for load balancing. Assuming a common communication radius of R, for multihop communication to be possible, it is necessary that R be large enough so that connectivity of nodes is guaranteed with a high probability of around 99%. To improve the connectivity, the probability of clustering to make more nodes to act as Cluster Head nodes is increased.

3.2. Path Data Centric Storage (PathDCS)

PathDCS [28] is an approach to data-centric storage that requires only standard tree construction algorithms, a primitive already available in many real-world deployments. This uses a few shared points of reference called landmarks and name locations by their path from one of these shared points of reference. The landmarks are a set of beacon nodes, which can be elected randomly or manually configured. To ensure that all nodes know how to reach the beacons, standard tree-construction techniques to build trees rooted at each one of these beacons is used. The overhead to establish the necessary state is proportional to the number of beacons. As this number is small, pathDCS imposes little overhead.

The number of hops required for each query or store is proportional to the diameter of the network, which is the same for all DCS approaches, multiplied by the number of segments. Thus, the key to keeping the overhead of pathDCS manageable is keeping the number of segments small.

3.3. Beacon Vector Routing (BVR)

BVR [29] defines a set of coordinates and a distance function to enable scalable greedy forwarding. These coordinates are defined in reference to a set of “beacons” which are a small set of randomly chosen nodes; using a fairly standard reverse path tree construction algorithm every node learns its distance, in hops, to each of the beacons. A node's coordinates is a vector of these distances. On the occasion that greedy routing with these coordinates fails, a correction mechanism that guarantees delivery is used. This results in initiation of scoped flood to find the destination. BVR ensures that packets can always reach their destination, flooding is an inherently expensive operation.

3.4. Greedy Hierarchical Virtual Protocol (HVP)

Greedy Forwarding with Hierarchical Virtual Position (HVP) [30] algorithm uses the combination of all K-level virtual positions (K>=1) and the geographic positions of nodes in a down-hill fashion. HVP requires nodes to store the geographic positions as well as all the K-level virtual positions of itself and its direct neighbors. A flag level is added to the packets to indicate the current level of virtual position. The down-hill process is uni-directional to ensure that HVP is loop-free. HVP fails if the lowest level virtual position (the geographic position) is already used and there is no neighbor to make further progress towards the destination of a packet. The down-hill process does not need to have a fixed decrement of 1. When using larger decrements, less levels of virtual position are needed, that implies less information storage on nodes. Dynamic decrements can be used when certain level of virtual position is missing.

3.5. Axis-Based Virtual Coordinate Assignment Protocol (ABVCap)

ABVCap [31] forwards the packet using the greedy method. ABVCap method is used to construct a virtual coordinate system in a WSN. The packet is first routed to a virtual node in the longitude region of the destination (longitude routing), then to a virtual node in the cell region of the destination (latitude routing), and finally to the destination using proactive routing. ABVCap assigns each node multiple 5-tuple virtual coordinates. Each node in ABVCap is assumed to be static, and has a unique ID and the same transmission range. A node with multiple virtual coordinates is perceived as multiple virtual nodes each with exactly one virtual coordinate. If a node receives a message, each virtual node contained in the node receives the message. A node broadcasts (or generates) a message, if one or more virtual nodes contained in the node broadcast (or generate) the message. The virtual coordinate of the destination received by the source is unique. **A**BVCap routing always route the packet from the source to the destination. ABVCap routing guarantees packet delivery without the computation and storage of the global topological features. ABVCap routing also ensures moderate routing path length.

3.6 Particle Swarm Virtual Coordinates (PSVC)

PSVC [32] is a distributed virtual coordinate assignment algorithm that employs Particle Swarm Optimization [33] to compute virtual coordinates for geographic routing. The selection of the reference nodes and the relaxation steps are similar to GSpring [34]. PSVC computes the coordinates of the reference nodes by modeling the hop counts between the reference nodes as a spatial distance in a manner similar to NoGeo [35]. The election of each reference node floods the net-work, but the cost per reference node is approximately $O(D) \approx O(\sqrt{n})$, where D is the diameter of the network and n is the network size. PSVC uses 4 reference nodes for 2D networks and 6 reference nodes for 3D networks. PSVC converges faster, achieves a lower hop stretch, and scales well up to large networks of 3,200 nodes compared to NoGeo. Also, PSVC makes no assumptions on the network topology and can naturally be extended to three-dimensional (3D) WSNs.

3.7. Virtual Cord Protocol (VCP)

The idea behind the Virtual Cord Protocol [36] is to combine data lookup with routing techniques in an efficient way. VCP accomplishes this by placing all nodes on a virtual cord, which is also used to associate data items with. A hash function is used to create values in a predefined range [S, E] and each node in the network maintains a part of the entire range. The routing mechanism relies on two concepts: First, the virtual cord can be used as a path to each destination in the network. Additionally, locally available neighborhood information is exploited for greedy routing toward the destination.

Joining of a new node only affects a small number of nodes in the vicinity and it is independent of the total number of nodes in the network. The insertion of a new node only affects $O(m)$ nodes, where m is the number of local neighbors. The final result of the join process is a virtual cord that interconnects all the nodes in the network. This cord supports efficient routing in the network.

Routing in VCP is done using the virtual cord. Additionally, local neighborhood information is exploited for greedy routing. Based on the established cord, VCP routing always lead to a path to the destination—it is not possible to run into a dead end. Additionally, VCP allows to take shortcuts whenever a physical neighbor with a virtual number is available that is closer to the destination.

4. Simulation

This paper makes use of OMNET++ 4.2.2 for simulation of the protocols analyzed. The parameters involved in this comparison are network lifetime of a node, energy consumption of nodes and average hop distance. The simulation is done over 35 sensor nodes that are randomly deployed in the simulation environment. Once the deployment is done, positions of each node remain static. The objective of the simulation is that all the nodes could send data to the base station which works as a sink. It is assumed that base station is connected to a CPU and thus has no memory or lifetime limitation in contrast to the sensor nodes. All the simulation analysis is done considering that 25 nodes send data at a time to the base station.

This paper uses 0.5 J as the initial energy on each node. For energy discharge, the simulation takes into account the MICA2 energy model for receiving and transmitting signals. Scaling has been done to simulate the real environment and the energy used thus is:

T=0.312 µJ/bit (for transmitting)

S=0.234 µJ/bit (for receiving)

The simulation is done over 100 rounds for each of the above seven routing protocol.

Considering a packet having three fields, source id, destination id and an integer message, the size of packet equals 96 bits. Thus energy consumed for each packet is:

T_p =96x0.312 that is approximately equal to 29.9 µJ

R_p= 96x0.234 that is approximately equal to 22.5 µJ

The simulation is done over 100 rounds for each of the routing protocol explained in section 3.1 to section 3.7.

Events in OMNET++ are sequential whereas in the case of real world they may occur in parallel. Thus, time taken for the node to die, will be much less.

4.1. Simulation results

This section shows the results of the simulation done for the above seven protocols.

Network lifetime of a node

Network lifetime is the time from the beginning of the experiment (turning all sensors on) until the moment when the first one died. Although other definitions exist this one reflects the worst case [37]. Figure 1 gives the time (mapped from the number of events/100) for which the simulation works, before first node dies.

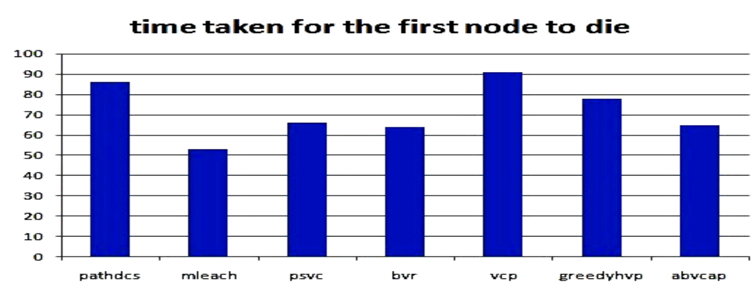

Figure 2. Shows time taken (no. of events/100) for the first node to die for each protocol

Energy consumption of nodes

Assuming that all the nodes have rechargeable batteries so that the nodes don't die due to loss of energy, the amount of energy used if 25 of the nodes send data to the base through 100 rounds is given in Joules as shown in the Figure 2:

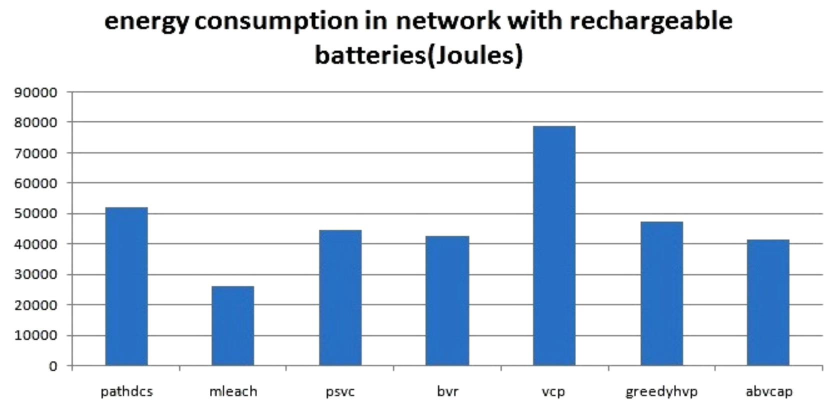

Figure 3. Total energy consumption of the network, assuming all the nodes have rechargeable batteries and do not die due to energy loss

Average hop distance

Five nodes are considered and the number of hops that the messages originated by these nodes cover to reach the base node are averaged over all the rounds. This is another parameter widely used to compare the seven protocols and is shown in Figure 3.

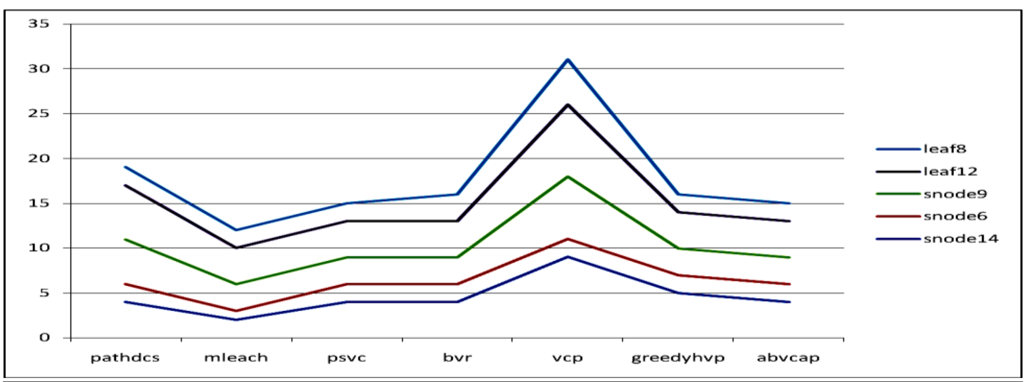

Figure 4. Average number of hops covered by messages generated by the five nodes

5. Conclusion

The paper analyzes seven different existing routing protocols namely, mLeach, pathdcs, BVR, ABVCap, PSVC, VCP and greedyHVP in WSNs on the basis of the lifetime of sensor networks. The performance of these protocols over lifetime metrics such as network lifetime, energy consumption of a node, and average hop distance is simulated on OMNet++ and the result analyzed.

The analysis of simulation result for the seven existing protocols in WSNs shows that the solution based on virtual coordinate assignment consumes less energy resulting in increase in lifetime of WSNs. However, routing protocols based on virtual coordinate normally proceeds by choosing some reference nodes known as *anchors*. These anchors are extensively used for initialization of virtual coordinates of all the other nodes and for routing between these coordinates. As a result, these anchors are prone to more loss of energy and thus shorter lifetime. When the total energy of the anchor (or of any other node) is used up, it creates a hole or dead end in the network which may lead to either failure of network functions or break the network.

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