Optimized Routing for Sensor Networks using Wireless Broadcast Advantage

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Abstract: - Routing in wireless sensor network is a challenging task. Barring a few applications, these networks would coexist with other wired and wireless networks. The proactive protocols do not fair well as the topology changes continuously due to the mobility of the nodes. Most of the reactive routing protocols have request reply pattern to establish a path and involves only sensors. These protocols deplete energy by control packets and have high latency. In this paper I propose a scheme which will eliminate the need for control packets by exploiting the wireless broadcast advantage. Also the proposed model is highly energy efficient when it coexists with other networks.

Keywords: - WSN, Routing, Wireless Broadcast Advantage, Energy efficient

1 Introduction

Sensor networks [19,32] have found application areas such as military, environment monitoring, intelligent control, traffic management, medical treatment, manufacture industry, antiterrorism and so on [24]. The key challenge in wireless sensor networks is to maximize network lifetime. Energy efficiency is the most important issue in wireless ad hoc networks and sensor networks. In event-driven networks, data is sent whenever an event occurs. In continuous dissemination networks, every node periodically sends data to the sink. The sensors send the sensed data to a control center or to a fixed destination.

In practice, the sensors will have varying transmission powers though homogeneity is assumed in sensor networks. Existing routing protocols for WSNs are built on the network architecture such that all sensor nodes are homogeneous and send their data to a single sink node by multiple hops [3, 6, 17, 26]. This architecture is not suitable for many real time applications with large-scale and heterogeneous sensor nodes.

Multi hop communication is used due to the limited transmission range of the sensors. Most of the routing protocols use only sensors as the next hop and thus deplete the energy of the nodes quickly. But in real life, the sensor networks would coexist with other networks except application specific networks such as underwater and forest networks. These are highly domain specific networks with predetermined topologies. But most other applications like traffic management, healthcare systems would coexist with other wired and wireless networks. In this paper, I argue to choose the nearest high energy node as the next hop instead of the next sensor to save energy and maximize the network life time.

Also the reactive routing protocols use request and reply packets to establish the path. This results in control packets overhead and energy loss. This paper proposes a scheme which exploits the wireless broadcast advantage for optimized routing. The nodes themselves decide on the best neighbour by listening to the broadcasts.

Simulation results show that this protocol outperforms the traditional routing approaches in terms of network lifetime and latency and is more suitable for real world applications. The remainder of the paper is organized as follows. Section 2 provides a brief overview of the related work. Section 3 explains the operation of the new routing protocol. Section 4 gives the proof for optimized routing. Section 5 gives the performance analysis of the protocols. Section 6 provides the conclusion of the work and discusses future directions.

2 Related Work

The review of the existing routing protocols can be found in [2, 7, 13, 20, 34]. Ad hoc on-demand distance vector (AODV) routing [22] combines both of modified on-demand broadcast route discovery approach used in DSR [15] and the concept of destination sequence number used in destination-sequenced distance-vector routing (DSDV)[23]. Directed diffusion [12] is a robust multi hop multi path routing and delivery protocol based on aggregation. This enables diffusion to achieve energy savings by selecting empirically good paths and by caching and processing data in-network (e.g. data aggregation). In [3, 5, 28] the authors have studied the various options for energy efficient wireless sensor network.

Location-based algorithms [18, 33] rely on the use of nodes position information to find and forward data towards a destination in a specific network region. In [33] Ye Ming Luz et al have proposed location based energy efficient protocol. Na Wang et al in [20] have studied the performance of the probabilistic multi path geographic based protocols. The position-based routing protocols are surveyed and classified into four categories in [34].

There is very less research work done related to sensor networks in heterogeneous [25] setup. Authors in [9] have proposed a secure routing protocol for heterogeneous sensor networks. In [1] the authors proposed a generic practical framework that optimizes media streaming in heterogeneous systems by taking advantage of cost and resource characteristic diversity of the integrated access technologies and the buffering capability of streaming applications. In [21, 31] the authors proposed localized topology control algorithms for heterogeneous wireless multi-hop networks. In [31] each node selects a set of neighbors based on the locally collected information. In [14] we have proposed a modified AODV protocol HLAODV which finds the nearest best neighbour and uses it as a hop. Still the protocol works by the way of sending and receiving control packets.

In [29] the authors have studied Minimum energy broadcast tree by exploiting wireless broadcast advantage. A measure of the broadcast advantage in a multi hop wireless network is given in [4]. In [8] TABS effectively combines the benefits of wireless broadcast advantages with traditional retransmission based routing while evades route explosion. In [10] the authors have proposed a bandwidth efficient multicast routing algorithm using WBA.

In this paper I propose an energy efficient routing protocol based on wireless broadcast advantage for sensor networks in heterogeneous setup.

3 System Model

A real time model is considered for the network set up. Typically when a sensor wishes to send data to the base station, it identifies the next hop neighbour and passes the data. This process continues till the data reaches the base station. Maintenance of such a network is crucial but at the same time it is prone to energy depletion as sensors are resource constrained devices. So an efficient approach is needed and I propose to make use of the other networks in the range of the sensor so as to save energy to prolong network life time. Also the wireless broadcast advantage is exploited to save energy from control packets overhead. Fig.1 shows the sensor distribution used in the scheme. The filled circles are the sensors, the circles are the mobile nodes and the square nodes are sink / high energy nodes. Every sensor node can establish a path either to a mobile node or to a high energy node in Fig.1 thus eliminates the transmission overhead. Also the broadcast messages of the high energy nodes are captured by the sensor nodes periodically. So the sensor nodes would always be ready with the next hop neighbour.

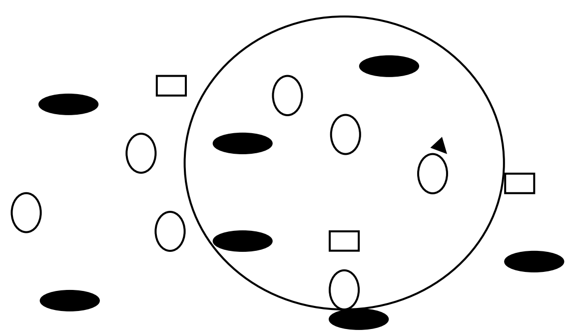

Fig.1 Sensor Distribution

Fig.2 illustrates the wireless broadcast advantage. When a node wants to transmit data, all the nodes in the region receive it. So, instead of sending and receiving request and reply packets, the nodes can overhear powerful nodes in the region and choose them as neighbours.

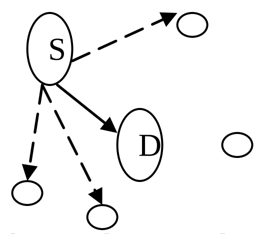

Fig.2 The Wireless Broadcast Advantage

The nodes broadcast their presence periodically. This includes their energy, location and status on mobility. Those nodes which need to send data listens to the broadcast and pick their next hops. Each node stores promising nodes. In selecting next hop, the first priority would be given to the maximum energy node or to a sink node within the transmission range. If a node finds a high energy node, then it need not store any other sensor nodes as neighbours. If the node happens to be a mobile mode, then the node has to keep the high energy mobile node as the next hop neighbour till it moves out of coverage. Location parameter is used when there is more than one high energy node. The closest high energy node would be the best next hop neighbour. Periodically the nodes would update their routing tables. In addition to that, the base station may notify the sensor nodes of the presence of high energy trusted nodes in their vicinity. In sensor networks, there are three possible types of transmissions.

1. Unreliable transmission
2. Guaranteed transmission
3. Secure transmission

3. 1 Unreliable Transmission

Each node chooses the best two neighbours and store in the routing table. The best neighbour algorithm works as follows:

1. The nodes would broadcast their energy level, status on mobility and current location.
2. If a node considers a node as a 'promising' node by energy level, location and trust worthiness, it adds it in the routing table.
3. The node will maintain the routing table for a period of 't' seconds.

The various scenarios for transmission are considered below.

1. Static node picks a static high energy node as neighbour – In this case the routing table is permanent. There is no need for searching for the best neighbour. This is applicable for stationary wireless sensor networks.
2. Static node picks a mobile node as neighbour – In this case, the routing table needs to be updated after the mobile node moves out of the transmission range of the node. This is done by periodically listening to the broadcasts. If the mobile node moves out, the listening node will have to pick a new neighbour.
3. Mobile node picks a static node – The routing table needs revision after the mobile node moves out of range of the static node. The mobile node would listen to the broadcasts periodically and thus determine whether it is within the range of the static high energy node.
4. Mobile node picks a mobile node - The routing table needs to be modified when the mobile nodes lose the coverage of each other.

3.2 Guaranteed Transmission

Often times, the sensor nodes would need to send guaranteed information to the base station. When the sensor nodes are engaged in reliable transmission, it is essential to acknowledge the receipt of packets. Here the same scheme as in case (i) is followed. But the data packet is modified with an acknowledgement request. The neighbour has to send an acknowledgement packet back to the source node. If the neighbour fails to send an ACK packet within time 't' seconds, the node resends the data to the next best neighbour. The guaranteed transmission works as follows:

1. Source node picks the best neighbour (next hop) as in (3.1).
2. Sends data packet to the next hop.
3. Next hop node sends an ACK packet back to the source node.
4. If ACK is not received within t seconds, choose the next best neighbour.

3.3 Secure Transmission

As this scheme is based on trusting the nodes with high energy, there is a possibility of a malicious node attracting the other nodes. This is called sinkhole attack [15] which prevents the base station from obtaining complete and correct sensing data. In a sinkhole attack, a compromised node tries to draw all or as much traffic as possible from a particular area, by making itself look attractive to the surrounding nodes with respect to the routing metric. As a result, the adversary manages to attract all traffic that is destined to the base station. By taking part in the routing process, the malicious node would do more harm by various attacks, like selective forwarding, modifying or even dropping the packets coming through.

To prevent this, the same scheme is used but with added features. The data packet is modified to include a secure transmission mode. To protect the integrity of the data, the data is not sent in clear but in an encrypted form. As sensor nodes are resource constrained devices, a light weight cryptography algorithm is used. In this scheme a variant of HB protocol [11] is used. The source node shares a key with the base station. The operation is simple XOR. Any other encryption algorithm can be selected depending on the security level of the content. The malicious node gets only encrypted data which can only be decrypted by the base station. Thus the integrity of the data can be maintained. The secure transmission works as follows:

1. Source node picks the best neighbour (next hop) as in (3.1).
2. Encrypt the data. (E(data)).
3. Send E(data) to the next hop.
4. If ACK mode is set , send ACK to the source node.

3.4 Algorithm

Neighbour Discovery
1. Node n listens for broadcasts.
2. Picks a neighbour based on energy level, location (N(i)).
3. If E(N(i)) > any E(N(j)), j = 1,2 and N(j) ∈ RT(n), Update Routing Table.
4. After a period ‘t’ seconds, Update Routing Table. Go to Step 1.

Transmission
1. If (mode = “Secure”) Encrypt data.
2. Else if (mode = “Guaranteed”) set ACK Flag.
3. Pick the neighbour from Routing Table.
4. Send data to next hop.
5. Go to listen mode.

3.5 Business Perspective

Topology management for WSN is crucial in prolonging the network life time. This is a major concern in sensor networks because of the dynamic nature of the topology. The stationary nodes would drain their energy and may not be able to participate in the transmission. The mobile nodes would also add to the complexity of the topology. Most of the sensor networks are application specific. In this context, the application layer will have topology information which can be shared with the network layer. The application providers can install high energy nodes based on the algorithm. The cross layer information can be shared between the application layer and the network layer. As each node helps other nodes to transmit data, the different vendors can get competitive in offering their services. The different service providers can charge the node that made use of their services. Thus cooperative routing is possible as each high energy node would compete to be selected as the next hop. This scheme would eliminate selfish nodes and it is beneficial to both the sides.

4 Optimized Routing

An important problem in WSN is finding a small connected relay set to assist in routing. Optimized routing can be achieved if all the nodes that sense the data are able to communicate to the base station in an energy efficient way. This section elaborates on the conditions of optimized routing.

Definitions

Optimized Routing: Optimized Routing is one that maximizes the network life time by minimizing energy consumption through efficient transmission in a multi hop communication.

Dominant Node: A node is said to be dominant if the transmissions that involve the node do not affect its energy level.

Energetic node: A node is said to be energetic, if the remaining energy E(v) is above the energy threshold. ET.

Covered node: A node v is said to be covered if there is at least one dominant node dv with radius r that includes both v and dv and is energetic.

Theorem: The necessary condition for optimal routing is covered nodes.

Proof: Consider a node v. Assume the radius ’r’ is equal to maximum transmission range of node v.

If there is a dominant node within its radius, distance covered is $d \leq r$, where d is the distance between the node and the dominant node. Otherwise the distance covered will be r+ d', where d' is the distance from the radius boundary to the dominant node.

Let E(v) be the energy level of the node. The parameters that are considered for optimality are

- Time
- Energy Conservation

i. Let d be the distance between the node and its base station. Let d1 be the distance between the node and the nearest sink node. By the design of the protocol, d ≥ d1 .

- In the best case i.e, if there is a dominant node within its radius, d >d1. This implies the time taken will be optimal.
- In the worst case, i.e, there is no dominant node within r. In that case d is equal to d1 and it implies that the time taken neither increases nor decreases. Therefore the time taken will be optimal.

ii. To prove energy conservation, consider any arbitrary node v. Assuming that most energy consumptions are caused by transmissions, the energy estimation is given by,

$$E(v)k+1 = E(v)k - m(v)kET(1)$$

where m(v) is the number of messages transmitted by node v at time k and ET is the energy consumed per transmission. Note that the proposed model assumes that the energy consumptions are the same at each transmission (which is a reasonable approximation if information is sent in packets of equal size), and that node v 'listens' all transmissions done by its neighbor. Also the number of transmissions is related to the number of hops that the protocol takes to deliver data. This model spares intermediate nodes as much as it can and thus the number of hops is small in one communication. Also this scheme does not have any control packets and so the number of transmissions is lesser compared to other protocols. Only dominant nodes participate in the routing process. If E(v) <ET (Threshold energy), v will not participate in routing. So there is very less energy level spent in the whole process. Thus it prolongs the network life time.

4.1 Mathematical Model

A WSN can be represented as a directed graph where each vertex represents a sensor and each edge is the link between two sensors. Links are associated with the energy level of the sensors. The model based on the metric used in the proposed scheme is called dominating set based model. The graph is drawn as below.

1. The nodes are placed as in their positions at time 't'.
2. Each node is assumed to be aware of the highest energy node. [This can be accomplished by making the high energy node simply broadcasting its status.]
3. Each node checks whether it can make a link with the high energy node.
4. If possible an edge goes from the node to the high energy node.
5. Otherwise the nodes choose the farthest node towards the high energy node and make an edge.

For example consider a WSN with 5 nodes. The node id and their energy levels are given in the pairs (1, 3), (2, 2.2), (3, 4), (4, 2.3), (5, 1.1). The highest energy node is 3. Assume nodes 1, 2 and 4 can reach directly to node 3 and node 5 can reach only 4. Node 4 can in turn reach node 3.So node 3 is the dominating vertex. Therefore the dominating set is {3}. The high energy node is called the dominant vertex. The problem is to construct a minimal dominating set (MDS) for WSN.

4.1.1 Construction

1. Represent the node and the edges using an adjacency matrix. [If two nodes are within the range of each other, represent as 1; Otherwise 0.]
2. Calculate the in degree of each node. [The number of 1's in each column.]
3. Find the maximum in degree node.
4. Add it to MDS.
5. Eliminate those nodes which have edges with it.
6. Repeat the process for the remaining nodes.

5 Performance Analysis

The protocol is simulated on GloMoSim, [26] a scalable discrete-event simulator developed by UCLA. This software provides a high fidelity simulation for wireless communication with detailed propagation, radio and MAC layers. The GloMoSim library [27] is used for protocol development in sensor networks. The library is a scalable simulation environment for wireless network systems using the parallel discrete event simulation language PARSEC.

5.1 Simulation Model

There are some initial values used in the simulation. Table 1 lists the assumed parameters. Intel Research Berkeley Sensor Network Data and WiFi CMU data from Select Lab [30] are used to get the positions for the nodes. The experiment is repeated for varying number of nodes. CBR traffic is assumed in the model. For mobility, trace file is used. The new protocol is written in Parsec and hooked to GloMoSim.

Table 1- Assumed Parameters

Parameters	Value
Transmission range	250 m
Simulation Time	5M
Topology Size	2000m x 2000m
Number of sensors	55
Number of sinks	16
Mobility	Trace File
Traffic type	Constant bit rate
Packet rate	8 packets/s
Packet size	512 bytes
Radio Type	Standard
Packet Reception	SNR
Radio range	350m
MAC layer	IEEE 802.11
Bandwidth	2Mb/s
Node Placement	Node File
Initial energy in batteries	10 Joules
Signal Strength Threshold	-80 dbm
Energy Threshold	0.001mJ

In Table 2, six nodes with their locations and their types are given. Type 0 is less energy stationary node, type 1 is rechargeable mobile node and type 2 is high energy sink node. In the table there are two high energy mobile nodes and one base station. The location is measured as (x,y) coordinates with an approximation factor given by the third parameter.

Table 2 - Sample Nodes

Node	Type	Location
0	0	(21.5, 23, 0.11)
1	1	(24.5, 20, 0.01)
2	2	(19.5, 19, 0.12)
3	0	(22.5, 15, 0.05)
4	0	(24.5, 12, 0.09)
5	1	(19.5, 12, 0.10)

Table 3 shows the routing table as maintained by node 0. It has two best neighbours, 2 as the stationary high energy node and 53 as a mobile high energy node within its range. Similarly each node maintains its own routing table by listening to the broadcasts and picks its best neighbours. The table would be updated periodically by the nodes as discussed in (3.1).

Table 3 - Sample Routing Table for node 0

Node	Nexthop	Type	Location
0	2	S	(19.5,19)
0	53	M	(26.2,2)

5.2 Performance Metrics

For the evaluation of protocols the following metrics have been chosen. Each metric is evaluated as a function of the topology size, the number of nodes deployed, location and the data load of the network.

- Hop count – The number of hops used by the protocol to reach the destination.
- Latency – This is a measure of execution time. It is the total time taken by the various protocols for the given CBR traffic to complete within the simulation time.
- Energy spent – This is measured in terms of signals received and transmitted. The energy spent on each node is directly proportional to the number of signals received and transmitted. Less number is an indicative of energy conservation.
- Load balance - The number of nodes used in the transmission. This is also an indication of energy conservation at each node.
- Control packets overhead – Most of the protocols use control packets to establish a path. These control packets would have an adverse effect on the traffic and the latency.

5.3 Simulation Results

Fig.3 shows the number of times a node is used as a hop for the given traffic by various protocols. The same traffic was assumed by the other protocols such as AODV and DSR. The proposed scheme has the least hop count compared to other protocols. This is because the node always chooses a high energy node as the next hop, sparing the stationary nodes. So the proposed model is highly energy efficient as most of the nodes are not used as next hop neighbours.

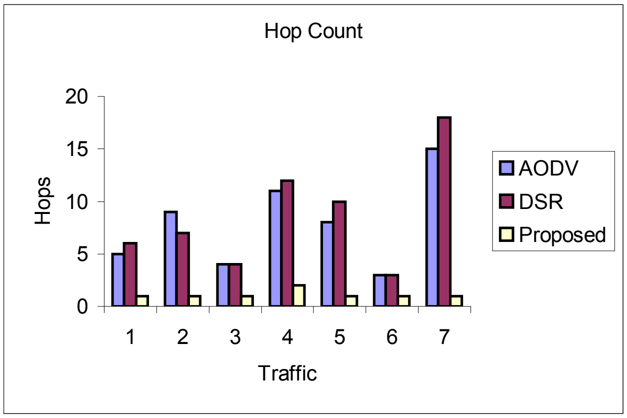

Fig.3 – Hop Count

Latency refers to the time taken to reach the destination. Here the simulated execution time is taken into consideration. Fig.4 shows the latency of various protocols for the given traffic. The simulation is also repeated with varying number of nodes. As in the figure, the proposed model has the least time. It is because of the best possible route that the protocol takes to reach the base station. It can be noted that even as the average traffic increases the proposed model tends to have low latency compared to other models.

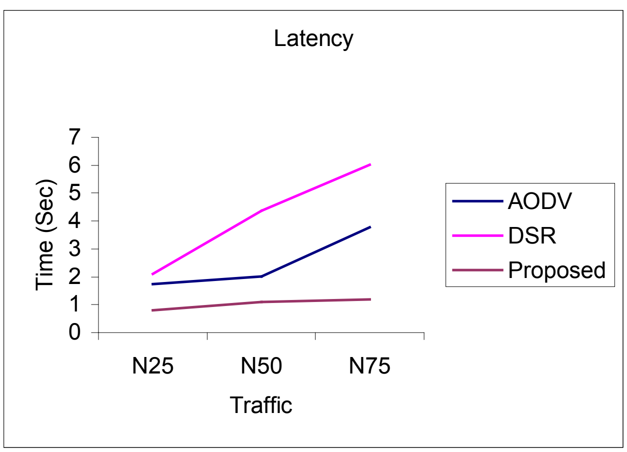

Fig.4 – Latency

Energy Savings is determined by the number of transmissions and receptions. When a node is used as next hop, it transmits and receives signals. The proposed model is based on wireless broadcast advantage and so the request and reply packets are avoided. Thus in the proposed scheme very few transmissions and receptions of signals causing significant energy savings as shown in Fig.5 and Fig.6. In related protocols almost all the nodes are affected by the selected traffic and thus resulted in decreased energy savings. Also it would lead to the complete drainage of a few nodes thus shortening the network life time.

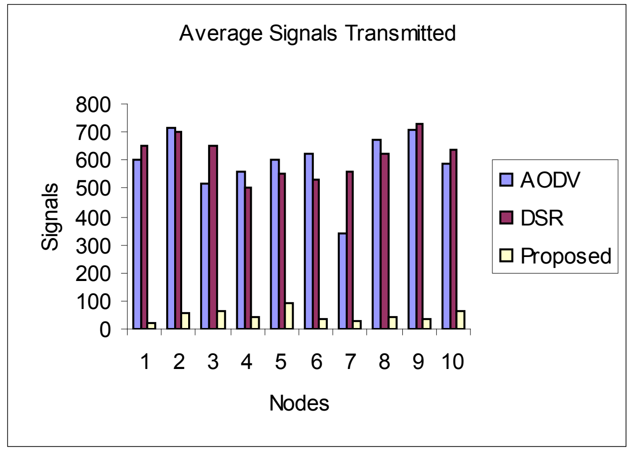

Fig.5 – Energy Spent on Transmission

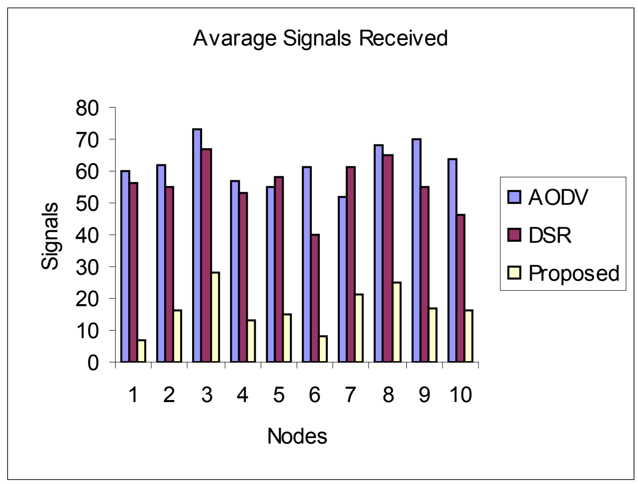

Fig.6 – Energy Spent on Reception

Load balancing refers to the number of nodes used in the transmission. If a node is frequently used in the transmission, the node would lose out all its energy soon. In this paper, it is proposed to use only high energy nodes as next hops. Only if there is no high energy node, the low energy stationary nodes would be selected as next hops. Fig.7 shows the usage of the nodes in the simulation. The high energy nodes are used more frequently and stationary nodes are almost spared from any communication. Load balancing based on energy in the proposed system is highly effective and prolongs the network life time.

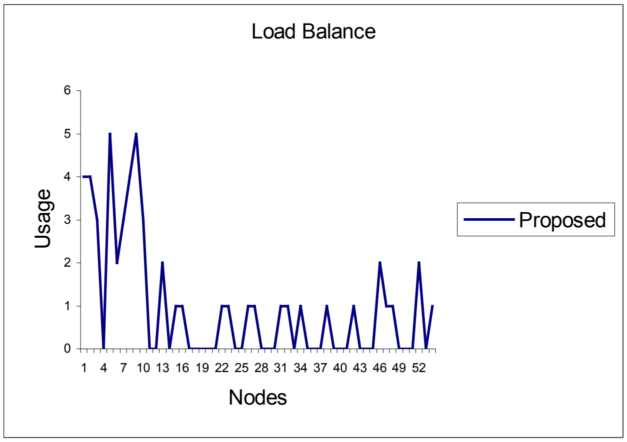

Fig.7 – Load Balancing

In addition to the data packets, the control packets would add to the traffic congestion and higher latency. Most of the existing protocols use request and reply packets to establish a path. Also these control packets would time out and then need to be sent repeatedly. This leads to control packets overhead. In the proposed model the wireless broadcast advantage is exploited. The nodes choose their neighbours by listening to the broadcasts. Thus control packets are almost totally eliminated in the proposed model. In guaranteed transmission, ACK packets are generated. It accounts for the positive number of control packets in Fig.8.

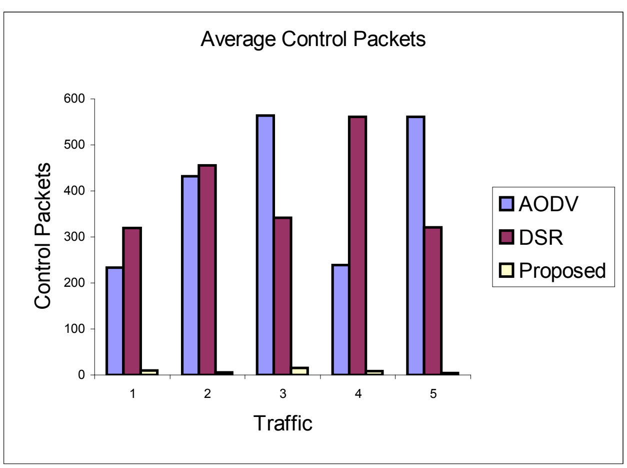

Fig.8 – Control Packets Overhead

6 Conclusion

An energy efficient routing scheme is proposed for sensor networks by exploiting the wireless broadcast advantage. This model completely eliminates control packets and picks only the high energy nodes for transmission. Also the model has addressed the different requirements of transmissions namely guaranteed and secure transmissions. When simulated, it has better energy savings compared to the other protocols. This model is suitable when the sensor network coexist with the other networks. However there is a small probability of picking a malicious node as the best neighbor in this model as the malicious node would advertise a high energy path. The secure more transmission suggested in this paper would take care of the above problem. If all the nodes are likely to have the same power the above model will not be very efficient. It will drain the slightly higher energy node soon.

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