A Power Aware Routing Strategy for Ad hoc Networks with Directional Antenna Optimizing Control Traffic and Power Consumption

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Abstract

This paper addresses the problem of energy-efficient and power aware data routing strategies within the ad hoc networks using directional antennas and considers the battery power of each node as an important criteria while determining the route for data packet transmission. Energy depletion of nodes in ad hoc networks is one of the prime concerns for their sustained operation. Conventional routing strategies usually focus on minimizing the number of hops or minimizing route errors from the source node to the destination node. But they do not usually focus on the energy depletion of the nodes. Thus, the same node may be selected repeatedly, thereby causing its early depletion in energy. In our proposal, if a node in the network has heavily depleted its battery power, then an alternative node would be selected for routing so that not only the power of each node is used optimally but there is an automatic load sharing or balancing among the nodes in the network. The usage of directional antenna has some key advantages which outperforms the omni-directional counterpart. The space division multiple access and the range extension capabilities of the directional antenna is itself a reason for its choice. The power requirement of the directional antenna is also much less than that of the omni directional version covering the same range. A salient feature of directional antenna is that it doesn't overhear the nodes outside its own cone of coverage and allows simultaneous communication without interference. This additionally helps to reduce power depletion of nodes. We illustrate how directional antenna can be combined with the power aware routing strategy and, using simulations, we quantify the energy benefits and protocol scalability. Our initial evaluation offer encouraging results, indicating the potential benefits of power aware routing using directional antenna.

1. Introduction

A group of wireless hosts forming a temporary network without any pre-existing infrastructure or without the aid of any centralized backbone is known as an Ad hoc network. In these kinds of environment the mobile hosts depends on the assistance of the other node in the network to forward a packet to the destination in case the destination node is multi-hop away from the source. Thus each node here acts as a router when the situation demands.

In an ad hoc network, one of the major concerns is how to decrease the power usage or battery depletion level of each node among the network so that the overall lifetime of the network can be stretched as much as possible. So while the data packets are sent from source to destination, special routing strategies need to be adopted to minimize the battery depletion level of the intermediate nodes. This paper addresses the problem of energy-efficient and power aware data routing strategies within the ad hoc networks using directional antennas and considers the battery power of each node as an important criteria while determining the route for data packet transmission. Conventional routing strategies usually focus on minimizing the number of hops or minimizing route errors from the source node to the destination node. But they do not usually focus on the energy depletion of the nodes. Thus, the same node may be selected repeatedly, thereby causing its early depletion in energy. In our proposal, if a node in the network has heavily depleted its battery power, then an alternative node would be selected for routing so that not only the power of each node is used optimally but there is an automatic load sharing or balancing among the nodes in the network. The usage of directional antenna [1,2] has some key advantages which outperforms the omni-directional counterpart. The space division multiple access and the range extension capabilities of the directional antenna is itself a reason for its choice. The power requirement of the directional antenna is also much less than that of the omni directional version covering the same range. A salient feature of directional antenna is that it doesn't overhear the nodes outside its own cone of coverage and allows simultaneous communication without interference. This additionally helps to reduce power depletion of nodes. We illustrate how directional antenna can be combined with the power aware routing strategy and, using simulations, we quantify the energy benefits and protocol scalability. Our initial evaluation offer encouraging results, indicating the potential benefits of power aware routing using directional antenna.

2. Related Work

A survey of power optimization techniques for routing protocols in wireless networks can be found in [3]. Suresh Singh, et al. [4] presented five power aware metrics in their paper and developed a new multi access protocol for ad hoc radio networks. The protocol is based on the original MACA protocol with the addition of a separate signaling channel. The unique feature of this protocol is that it conserves battery power at nodes by intelligently powering off nodes that are not actively transmitting or receiving packets. The manner in which nodes power themselves off does not influence the delay or throughput characteristics of the protocol. However, the power balancing among the nodes cannot be guaranteed, thereby causing non-uniform power conservation characteristics of nodes.

An online approximation algorithm for power-aware message routing has been proposed in [5]. They have developed an algorithm that requires accurate power values for all the nodes in the system at all times. They further proposed a second algorithm which is hierarchical, known as Zone-based power-aware routing. It partitions the ad-hoc network into small number of zones. Each zone can evaluate its own power level. These power estimates are then used as weights for the zones. A global path for each message is determined across zones. Within each zone, a local path for the message is computed so as not to decrease the power level of the zone too much. However, they assume that accurate power values for all nodes are known which is not realistic. Moreover, formation of hierarchical zone and its maintenance is a serious problem in dynamic ad hoc networks.

In our proposed strategy, each node knows the approximate battery power status of other nodes and uses it as one of the primary criteria for route selection. Each node is also aware of the approximate topology of the network. This is done through periodic propagation of power information along with topology information. To minimize the power usage, directional ESPAR antennas [6,7] have been used. We illustrate how directional antenna can be combined with the power aware routing strategy using a modified version of a proactive protocol, developed in our earlier work [6].

3. System Description

In order to fully exploit the capabilities of directional antenna, all the neighbors of a source and destination should know the direction of communication so that they can initiate new communications in other directions, thus preventing interference with on-going data communication between source and destination. Thus, it becomes imperative to have a mechanism at each node to track the direction of its neighbors and get some vital information like power status and neighborhood information.

3.1 Antenna Model

A model of an ESPAR antenna, a low-cost, low-power, small-sized smart antenna developed at ATR [7], has been used in our simulation experiments. The features of ESPAR are: controlling beam direction, multiple beams (with same frequency) formation, steerable beam (360 degree sweeping) and controlling null steering. For receiver application, the null should be steered in the direction from which an interfering signal is coming. ESPAR antenna would help to reduce the power consumption of the user terminals and would be able to deliver all the advantages of directional antenna.

3.2 Location Tracking and MAC Protocol

In our framework, each node waits in omni-directional-sensing mode while idle. Whenever it senses some signal above a threshold, it enters into rotational-sector-receive-mode. In rotational-sector-receive mode, node n rotates its directional antenna sequentially in all directions at 30 degree interval, covering the entire 360 degree space in the form of the sequential directional receiving in each direction and senses the received signal at each direction. After one full rotation, it decides the best possible direction of receiving the signal with maximum received signal strength. Then it sets its beam to that direction and receives the signal. Thus, in order to track the direction of its neighbor using directional antenna, each node n periodically collects its directional neighborhood information so that a node can determine the best possible direction of communication with any of its neighbor. We have used three types of broadcast (omni-directional) control packets: Global Link State Table (GLST), RTS (Request to send) and CTS (clear to send) for medium access control. Data packets and the control packet ACK is a directional control packet [8,9]. A detailed description of directional MAC is illustrated in [8,9].

3.3 Information Percolation Mechanism in the Network

The purpose of information percolation mechanism is to make each node aware of the approximate topology and the power depletion status of each node in the network. The objective here is to get accurate local perception, but approximate global perception of the network information. This approximate network awareness would be helpful to implement both MAC and a power-aware routing protocol using directional antennas.

3.4 Global Link-State Table (GLST)

It contains the global network topology information as well as the battery power status of the corresponding nodes as perceived by a node n at that instant of time. Each node broadcasts a beacon at a periodic interval, say T_A. When a node n receives a beacon from all or any of its neighbors (say node i, j and k), node n forms the GLST(n) to include node i, j and k as its neighbors and records the best possible direction of communicating with each of them. Initially when the network commences, all the nodes are just aware of their own neighbors and are in a don't-know-state regarding the other nodes in the system. Periodically, each node broadcasts its GLST as update to its neighbors. With this periodic update messages from its neighbors about their neighbors, the nodes slowly get information about the other nodes and their neighbors [6]. Each node broadcasts its GLST at a periodic interval, say, T_G. The structure of a GLST packet at any node n is given in Table 1. Every node decrements this residual power status whenever they transmit or receive a packet by a factor depending on the scheme [10].

Table1. The structure of GLST

Nodes	**Recency**	**Neighbors**	**Residual Power**
n_1	R_1	$\rightarrow \{\ldots\ldots\ldots\ldots\}$	P_1
n_2	R_2	$\rightarrow \{\ldots\ldots\ldots\ldots\}$	P_2
...	...	$\rightarrow \{\ldots\ldots\ldots\ldots\}$	P_3
n_i	R_i	$\rightarrow \{<n_j,\alpha(n_i,n_j)> <n_k,\alpha(n_i,n_k)>\ldots\ldots\ldots\}$	P_4
...	...	$\rightarrow \{\ldots\ldots\ldots\ldots\}$	...
n_N	R_N	$\rightarrow \{\ldots\ldots\ldots\ldots\}$	P_N

Here, R_i is the recency of node n_i in a network of N nodes and $<n_j,\alpha(n_i,n_j)>$ denotes that n_j is a neighbor of n_i where $\alpha(n_i,n_j)$ indicates the transmission beam-angle "α" at which n_i can best communicate with n_j. It is to be noted that the mechanism does not guarantee that each node would know the exact status of the network. It is merely an awareness that helps each node to figure out the approximate status of the network.

By controlling the periodicity of updates for GLST or beacons, it is possible to control the update-traffic in the network and the accuracy of network status information stored in each node. For example, if the propagation of update messages is too frequent, the control traffic will increase but the accuracy of network status information stored in each node will also be better. However, the network would get flooded with propagation of updates. The overhead can be controlled by adjusting T_A and T_G. Current values of T_A and T_G are 200 milliseconds and 10 seconds respectively. The optimization issues are discussed in section 6.

4. Power Aware Routing Strategy

A lot of effort is currently going on to reduce the power consumed in a mobile device within the ad hoc network and our power aware routing strategy can ensure optimal usage of battery power of each node. It is to be noted that our proposed strategy not only balances the battery usage of each node extending the network life but it also ensures network traffic balancing when the congestion is high.

To enhance the efficiency of data communication, shortest path algorithms are usually used. But, if only shortest path algorithm is used, then it will be observed that the intermediate nodes in that shortest path will deplete their power much more early then their neighbors. Consider the following topology, as shown in figure 1:

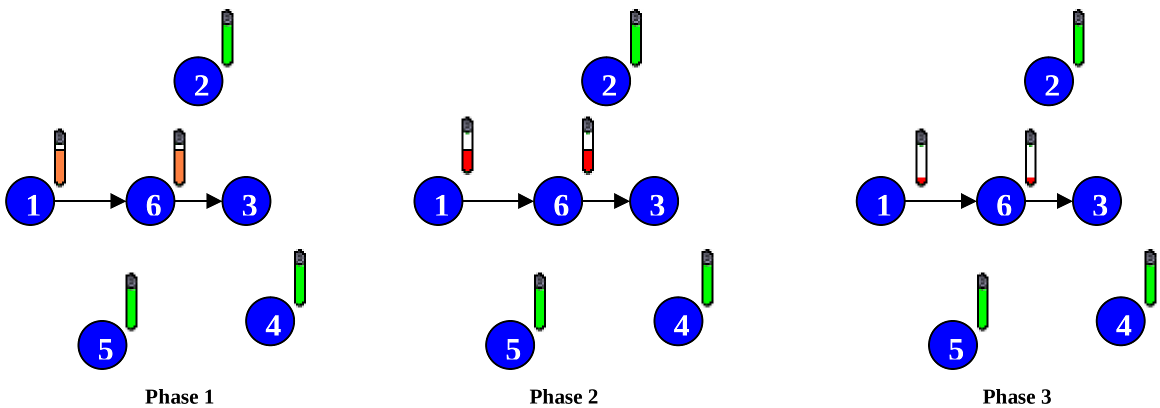

Figure 1. Battery Status without Power Aware Routing following only Shortest Path Algorithm

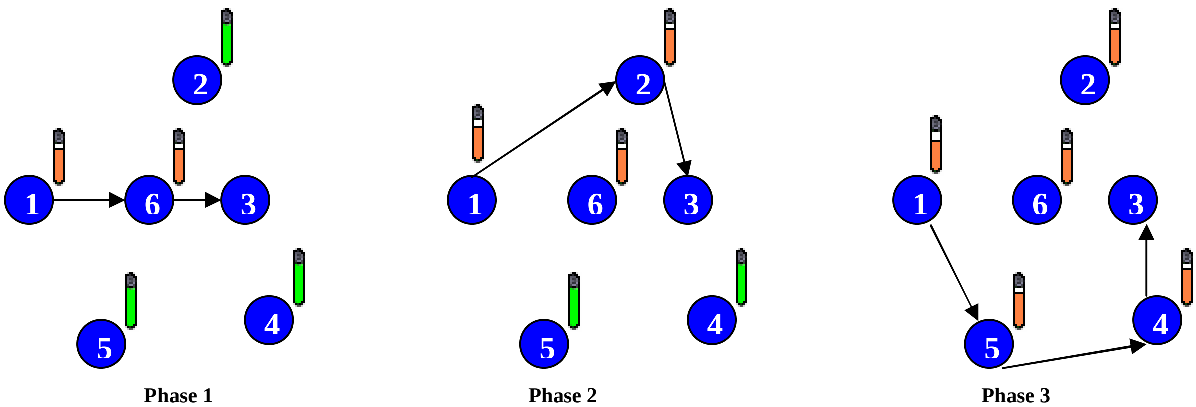

Figure 2. Battery Status with Power Aware Routing together with Shortest Path Algorithm

In Figure 1, packets are to be sent from node 1 to node 3. Let us assume that the shortest path algorithm selects 1 -> 6 -> 3 as the best path. Disregarding the source node 1 and destination node 3 (which are fixed in this case), it will be observed that the intermediate node 6 will suffer heavy depletion in its battery power because only node 6 is selected repeatedly as intermediate node by the shortest path algorithm.

Now let us shift our focus on our proposed algorithm for route selection using residual power aware routing strategy. Figure 2 represents the case where data packets are forwarded using this strategy from the same source to destination. After phase 1, the battery of intermediate node 6 has depleted by 10 % (say) and so in phase 2, node 6 will not be considered. An alternate path 1 -> 2 > 3 will be selected, since node 6 has less battery power than that of node 2. Now let us consider phase 3 in figure 2. Both node 2 and 6 have depleted their power by 10% (say). For transmission of next set of data packets, both the intermediate nodes would be rejected and intermediate nodes 5 and 4 will be selected (1 -> 5 -> 4 -> 3), since they have their battery power much higher than node 3 and 6. It is to be noted that not only the power is used optimally but there is an implicit property of the algorithm to automatically balance the network traffic and distribute it in an even fashion choosing different paths from source to destination.

5. Simulation Environment

The simulations are conducted using QualNet 3.1 [11] network simulator using the ESPAR antenna model. 60 nodes are placed over 1000 x 1000 sq. meter area using the grid topology. Nodes are randomly chosen to be CBR (constant bit rate) sources, each of which generates 512 bytes data packets to a randomly chosen destination at a rate of 2 to 500 packets per second. The set of parameters used is listed in Table 2.

Table 2. Parameters used in Simulation

Parameters	Value
Area	1000 x 1000 sq. m
Number of nodes	60
Transmission Power	10 dBm
Receiving Threshold	-81.0 dBm
Packet Size	512 bytes
Initial Battery Power of each node	2400000 units
Total Number of simultaneous CBR Traffic	3
CBR Packet Arrival Interval	2 ms to 500 ms
GLST Periodicity (T_G)	10 second

5.1. Simulation Scenario

We have studied the effects of our proposed strategy in static as well as in mobile scenarios. Initially we assume all the nodes have same power and observe the residual power characteristics of each node at the end of the simulation using and without using the power aware routing strategy. The entire simulation period is of 7 minutes and 3 source-destination pairs are chosen in random. The CBR traffic is applied simultaneously from the three sources starting from the 2nd minute and terminating at the 6th minute. In case of the mobile scenario, we keep the same topology and same source-destination pairs for the CBR traffic. Each node is given random motion ranging from (0 to 10) m/sec. In the simulation we have considered that depletion of battery power occurs only during transmissions. So we decremented the total battery power levels by a factor each time a packet were transmitted. The decrement factor is basically the product of 1400 and (1 % of the packet size being transmitted). It is to be noted that the source nodes for CBR traffic are bound to get the maximum power depletion which is true in any case. So to understand the power depletion characteristics of the nodes, the source nodes are taken out of consideration and are assumed to have constant initial power.

5.2. Simulation Results

Power Depletion Graph for the Static Scenario

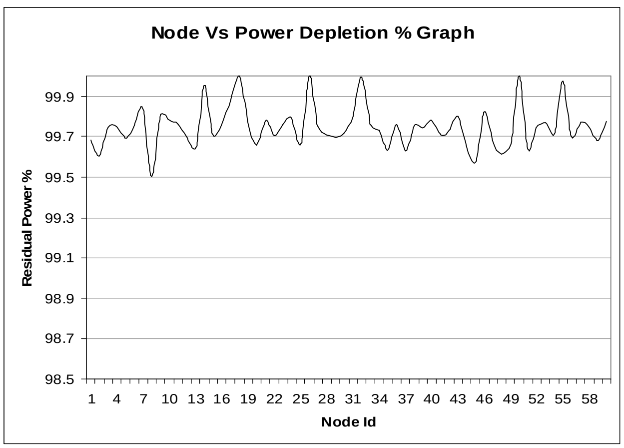

Figure 3. a. With Power Control

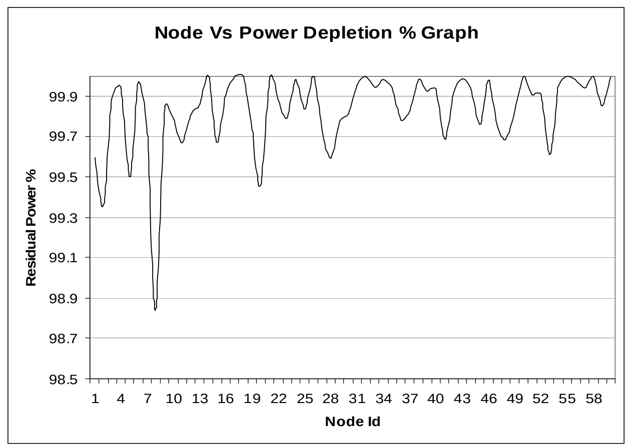

Figure 3.b. Without Power Control

Power Depletion Graph for the Mobile Scenario

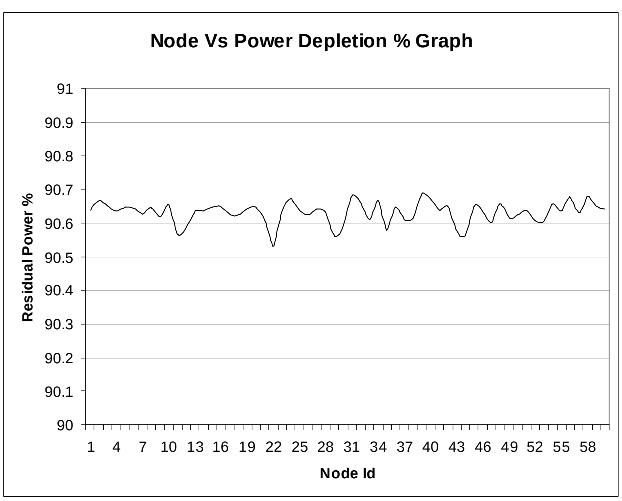

Figure 4. a. With Power Control

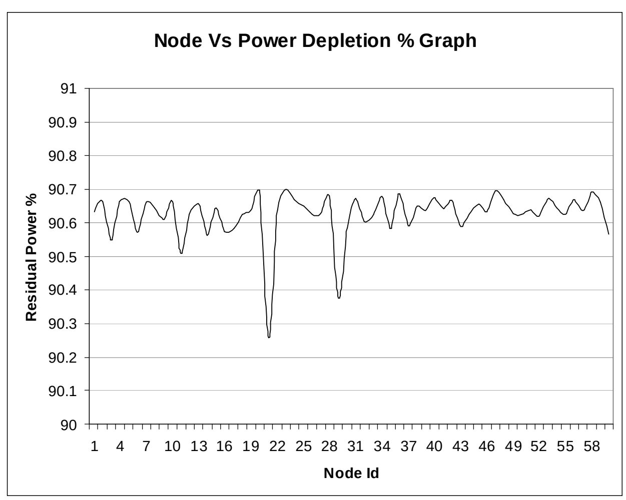

Figure 4.b. Without Power Control

Figure 3a and 3b shows the power depletion graphs in a static scenario. Figure 3a represents the nature of power depletion characteristics among the nodes when our power aware routing strategy is used. Figure 3.b on the other hand shows the power depletion characteristics without our power aware routing strategy but using only the shortest path algorithm. A close study reveals the fact that some nodes in Figure 3.b suffer heavy depletion, although most of the nodes have nearly the same initial power. These results in early die out of some nodes in the network and thus the entire network may get partitioned into two or more sub networks. In other words, multi-hop communication would be restricted to a great extent because the intermediate nodes have died out much earlier than the neighbors which still have more battery power. Now shifting our focus on figure 3.a which shows the power depletion graph characteristics when our power aware routing strategy is used. This graph represents a uniform power depletion curve, leading to increased life-time of the network.

Figure 4.a and 4.b demonstrates the power depletion characteristics of the node in a mobile scenario. Here the nodes are mobile with a random velocity ranging from 0 to 10 m/sec. It may be noted that even in this scenario the power aware routing algorithm performs much better then its counterpart, thereby making this strategy ideal for both static and mobile scenarios.

5.3. Throughput

Figure 5a and figure 5b represents the throughput of the network in a static and a mobile scenario respectively with or without the power control strategy. The underlying reason for improved throughput with power-aware routing is the automatic load balancing nature of the algorithm, as illustrated in section 4.

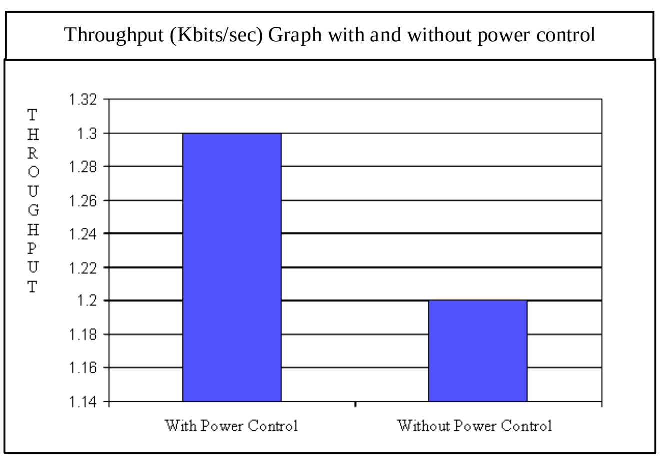

Figure 5.a. Throughput in Static scenario

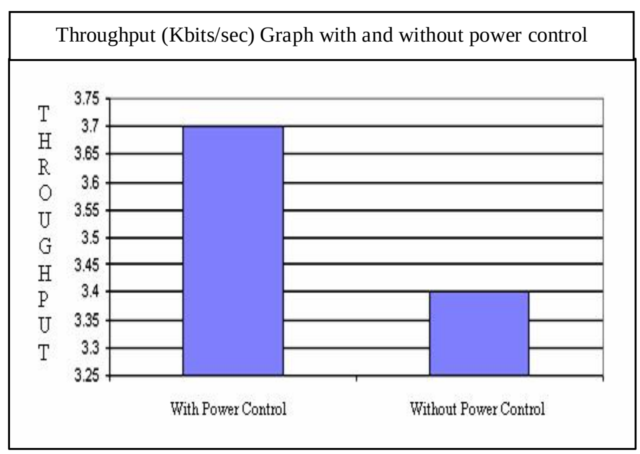

Figure 5.b. Throughput in Mobile scenario

6. GLST Optimization

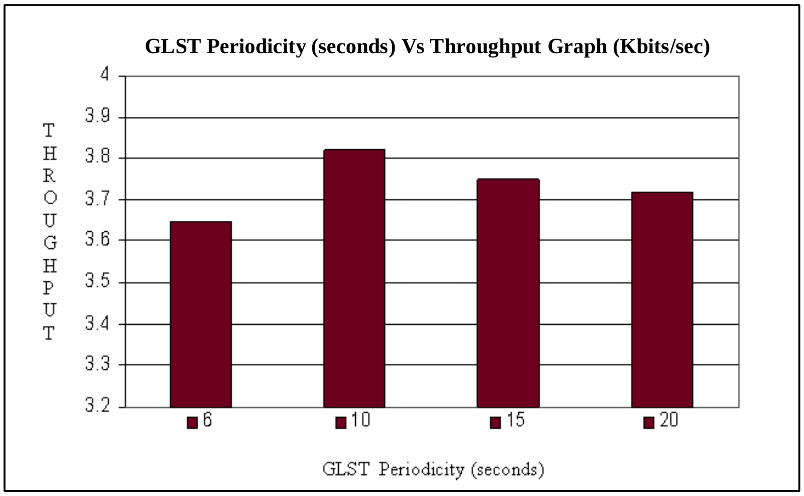

Figure 6. GLST Periodicity vs Throughput in Mobile scenario

A GLST packet contains the network status information as perceived by a node (n) at that instant of time. As illustrated earlier, if the periodicity of GLST packet transmission is very fast, then there will be an unnecessary load in the network which may result in packet collisions and useless power depletion among the nodes. On the other hand, if the GLST transmission periodicity is slow, then the nodes will not get the updated information about its neighbors and this may result in higher probability of packet loss and usage of old routes for transmission although better paths exists.

For the above reasons it is highly recommended to choose a proper periodicity for GLST propagation, so that it produces an optimal throughput to the problems stated earlier. Using the Qualnet Network Simulator, and the same topology as taken earlier for all our experiments, various GLST transmission periodicity were tested. Finally their throughput was plotted against the GLST periodicity for the mobile scenario. Figure 6 shows the throughput for the GLST periodicity for mobile scenario. From the figure, it is evident that 10 seconds is the periodicity of GLST that produces the maximum throughput.

7. Conclusion

In this paper, we present a power aware routing strategy for ad hoc networks with directional antenna optimizing control traffic and power consumption. This strategy mainly optimizes the power depletion and maintains a more or less uniform power usage among all the nodes in the network while maintaining effective throughput. In our simulation, we observe a sharp performance and power usage gains using the proposed algorithm.

8. References

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