Gateway Selection Review in Ad hoc Networks

Tarek R Sheltami
King Fahd University of Petroleum and Mineral
Computer Engineering Department
Dhahran, Saudi Arabia, 31261
tarek@ccse.kfupm.edu.sa

Abstract— **The nature of wireless mobile ad hoc networks depend on batteries or other fatiguing means for their energy. A limited energy capacity may be the most significant performance constraint. Therefore, radio resource and power management is an important issue of any wireless network. There is a need to reduce interference by controlling transmit power of the Mobile Terminals (MTs). Power aware design and estimation of transmit power requires familiarity with the energy consumption behavior, path loss, and interference of wireless systems. Moreover, selection of gateways, in case of availability of more than one gateway, has not been introduced thoroughly. Gateways maintain connectivity of the network and integrate two types of networks with each other. This paper introduces a mathematical analysis of power adjustment to control the transmit power using maximum transmission range and intermediate node methods for sending packets. We use these equations in selecting gateways in the simulation experiments according to two different criteria: the gateway with the highest energy level and the gateway with the least number of neighbors.**

Index Terms— **Clusterhead, gateways, ad hoc network, energy efficient**

I. INTRODUCTION

A wireless mobile Ad hoc network is a collection of wireless mobile hosts forming nodes, which are randomly changing their locations, communicating without the aid of any centralized administration or standard support services. Each node participating in the network acts both as a host and a router. In cluster-based routing protocols [5][6], gateways are used to maintain communication between two or more clusterheads. Selecting the appropriate gateway is an open point for discussion. In current cluster-based routing protocols, selecting gateways is mostly random, which is not a power aware approach. It has been documented that using small hops is optimal to reduce the transmit power level [1][8], if one wants to increase the traffic carrying capacity of the entire network. Hop count was typically the measure of routing, therefore, a constant metric per hop was used. The constant metric should be replaced with a power metric were mobile terminals adjust their transmit power depending on the distance of their neighbors [13][14] The Common Power (COMPOW) protocol [2][3] proposes that all the nodes transmit at the same power to ensure bidirectional links. Their argument is that: since all physical paths taken by radio waves from node X to node Y can be reversed, by multi-path or reflection, and the attenuation is the same in either direction, it follows that if two nodes X and Y transmit at the same power, then if X can hear Y, it will follow that Y can hear X. COMPOW shows that choosing the smallest range subject to maintaining network connectivity maximizes the traffic carrying capacity. However, power control also impacts on battery life time. The below mathematical analysis from [2]:

$$P(t) = P_i \text{ if } N(P_i)$$
$$= N(P_{max}) \text{ and } N(P_j) < N(Pmax) \; \forall \; P_j < P_i$$

Where,

$N(P_i)$: the number of entries in the routing table corresponding to the power level P_i at a node.

$P(t)$: Power level at time t

Each node chooses its power level based on the information contained in its own routing tables.

Another protocol in [12], Cluster Power (CLUSTERPOW) protocol divides the network into virtual clusters with no clusterheads. We can consider the COMPOW protocol as a special case of CLUSTERPOW protocol. The network consists of hops of different transmit power such that it is divided into clusters according to transmit power as in Fig. 1.
However the performance of the CLUSTERPOW protocol was not thoroughly tested, the only application in [12] was with Destination Sequenced Distance Vector (DSDV) protocol, which is proven to be very inefficient in ad hoc networks. Moreover, the protocol itself is rather complex.
A simulation experiment in [2] shows that low power transmission does conform with power aware routing, since power aware routing prefers many short hops to a long ones. Also, another simulation experiment in [2] shows that low power level minimizes the contention on the MAC layer.

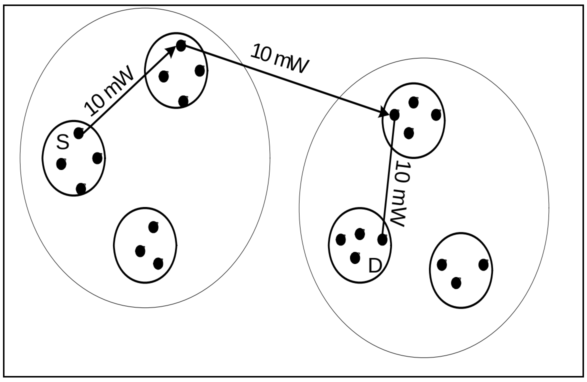

Figure 1: CLUSTERPOW protocol

In radio propagation, three basic mechanisms are usually considered for indoor and outdoor applications:

1. Reflection and transmission: that occur when the signal intrude on impediments larger than its wavelength.
2. Diffraction: a second source created by signal incidence on the verge of obstructions.
3. Scattering: signals scatters after hitting rough surfaces automobiles, etc, forming spherical waves, which reduces power levels.

In wireless ad hoc networks, cluster-based architecture is one of the most important approaches for many applications. Cluster-base architecture divides the network into several zones. Each Zone consists of a clusterhead and others node associated with it. Clusterheads are elected based on upon agreed rule (smallest ID, most connected node, energy level…etc). A clusterhead may act as gateway if it is communicating two different zones. Cluster-based protocols organize the network into a hierarchical structure to manage the network in an efficient way.

II. Path Loss Modeling

Calculation of transmit signal is influenced by many factors depending on the location. Therefore, one model can not be generalized. However, the prime factor of transmit in any environment is path loss calculation. It is very important to calculate path loss in order to adjust correctly the transmit signal. It is perceived that the electromagnetic signal strength decreases with distance. That is, the transmit power, Pt, after distance, d in meters, will be Ptd-α, where α is the path loss gradient (usually 2 or 4) [4].

In general, assuming α = 2:

Where,
P_r: the received power
G_t & G_r: antenna gains for transmitter and receiver respectively
λ = C/f, C: the speed of light and f: the frequency of the wave carrier

In the above equation, heights of the transmitter and receiver were not considered

In [4], $10 \log(P_r) = 10 \log(P_o) – 10\, \alpha \log(d)$
Therefore, $L_p = L_o + 10\, \alpha \log(d)$

Where,
P_o: the received power at distance of one meter
L_o: Path loss at distance of one meter
Lp: path loss at the receiving node

III. Power Analysis

In this section we assume that the direction to the destination is known, we can use protocols such us in [5][6] to provide this info.

In simple radio model presented in [10], radio dissipates E_{ele} = 50 nJ/bit at the sender and receiver sides. Let us assume the d is the distance between the source and destination, then, the energy loss is d^2. The transmit amplifier at the sender consumes $E_{amp}d^2$, where Eamp = 100 pJ/bit/m^2. Therefore, from the sender side, to send one bit at distance d, the required power is Eele + $E_{amp}d^2$, whereas at the receiver will need is E_{ele} only. Normalizing both by dividing by E_{amp}:

$P_t = E + d^2$ and $P_r = E$, where P_t and P_r are the normalized transmission and reception power respectively, and $E = E_{ele} / E_{amp}$ = 500m^2

At the HCB-model, the power needed for transmission and reception at distance d is:

$$u(d) = P_t + P_r = 2E + d^2$$

In [11],

$$u(d) = ad^{\alpha} + c$$

Where in HCB-model α = 2, a = 1, and c = 2E = 1,000 and RM-model, where α = 4, a = 1, and c = 2*108. However, we will be dealing with HCB-model in this paper.

Let us assume that the source S can reach the destination D directly. Let us further assume that there is middle node between the source and the destination. Let |SA| = x and |SD| = d as in Fig. 2.

[11] proved that if $d > (c/(a(1-2^{1-\alpha})))^{1/\alpha}$, then there is an intermediate node A between the source and destination such that the retransmission of the packet through A will save the energy. Moreover, the greatest saving is achieved when A s in the middle of SD.

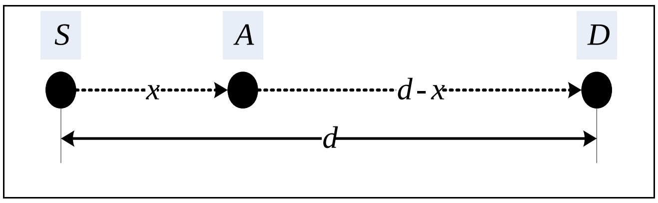

Figure 2: Sending packets through intermediate node

Also in [11], if $d > (c/(a(1\text{-}2^{1-\alpha})))^{1/\alpha}$, then the greatest power saving are obtained when the interval SD is divided into n > 1 equal subintervals, where n is the nearest integer to $d(a(\alpha\text{-}1)/c/)^{1-\alpha}$.

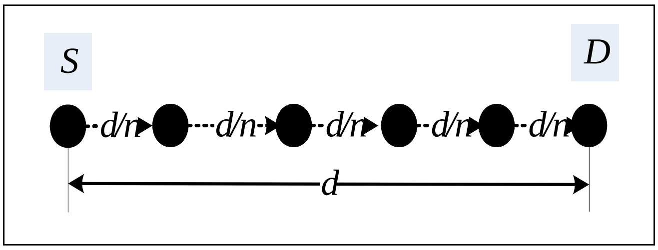

Figure 3: Optimized Route from S to D

Now the power needed for direct transmission is $u(d) = ad^{\alpha} + c$, which is optimal when $d \le (c/(a(1\text{-}2^{1-\alpha})))^{1/\alpha}$, otherwise when $d > (c/(a(1\text{-}2^{1-\alpha})))^{1/\alpha}$, n-1 is equally spaced nodes can be selected for transmission,
Where, $n = d(a(\alpha\text{-}1)/c/)^{1-\alpha}$ [14].
Substituting $\alpha = 2$, at the end of their derivation, the authors in [14] came to the conclusion that:

a) For direct transmission:

$$u(d) = ad^2 + c$$

Where, $d \le (2c/a)^{½}$.

b) For intermediate node retransmission:

$$v(d) = 2d(ac)1/2$$

Where, $d > (2c/a)^{½}$.

For HCB-model, the optimal value of n is 0:031d. However, this scheme is good only if the intensity of the network is not high, otherwise the energy consumption from S to D will in the order of $nO(n^2)$, because each time the packet is forwarded the neighbors will b affected.

An ad hoc network is modeled as a graph $G = (N, L)$, where N is a finite set of nodes and L is a set of bi-directed links.

The below analysis is applicable to direct transmission using up to maximum transmission range and intermediate node retransmission alike.

1. A node n_i has a set of neighbors, $NB_i = \{n_j \in N : (n_i, n_j) \in L\}$
2. A clusterhead V_i has a set of MTs, $MT_i = \{(n_i, V_i) \in N, n_i \in V_i, (n_i, V_i) \in L\}$, provided that n_i is within the transmission range of V_i.
3. A node ni has an intermediate set of gateways to a given destination.

$$g_i = \left\{n_j \in N, (n_i, n_j) \in L\right\}$$

A. Assumptions

- All nodes use the full transmit power in the hello message. In ad hoc networks, the typical maximum transmit power is 1 Watt.
- All power calculation is based on the received signal strength (RSS) in the hello message.
- The path loss gradient, α, equals 2.

1. For BER=10^{-6}, DQPSK modulation: $E_b/N_0 = 11.1dB$ [7].
2. Calculate E_b/N_0:

a. X=S/N*B/RATE.

b. If $X < E_b/N_0$, then reject it, else accept packet.

3. Receiver sensitivity:
P_r, min = receiver noise floor + S/R

a. *Receiver noise floor = $N_{fig} + N$*

where,
Noise Figure:
N_{fig}=10log10N_o-10log10G_d-(-174 dB+10log10B_r),

Typically, N_{fig} = 15 dB
N_o = measured noise
G_d = device power gain
B_r = receiver bandwidth
N: Boltzmann's constant, N = kT Br
k: Boltzmann's constant = 1.380650x10-23 J/K;
T: the effective temperature in Kelvin, and
B_r: the receiver bandwidth

b. Path Loss $(L_p) = L_o + 10\,\alpha \log(d)$

where:
d_{max} = maximum possible distance between transceivers.
$d > (c/(a(1\text{-}2^{1-\alpha})))^{1/\alpha}$

4. $P_{t,\,min} = P_{r,\,perv} + L_p$ + *Fade Mragin*
5. $P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$ assuming α = 2
6. Find $P_{t,\,min,\,i}$ for d, $P_{r,\,prev,\,i}$ using (4) and (5).

where,
P_t, min, i is the minimum required transmit power by node nj to node n_i
$P_{r,\,prev,\,i}$ is the pervious received power by node n_j from node n_i

a. Before an intermediate node n_j, on the route forwards its packets to the next node, it enters $P_{r,\,perv,\,i}$ calculated in (6)

b. Node n_i uses $P_{r,\,prev,\,j}$ entered by n_j to calculate its $P_{t,\,min,\,j}$.

B. Highest Energy Level and Least Number Of Neighbors Schemes

In our study we introduce two methods to select gateways, namely: gateways with the highest energy level (HEL) and/or those with the least number of neighbors (LNN).
The first method balances the energy consumption among the gateways, it keeps them alive as much as possible. On the other side, the gateways with HEL might have large number of neighbors, which they will be affect by its transmission. The energy consumption in this case is in the order of $O(n^2)$, which will greatly affect the energy consumed on the network as a whole. Neighbor Knowledge Methods

maintain state on their neighborhood, via Hello packets helps in selecting the appropriate gateway.

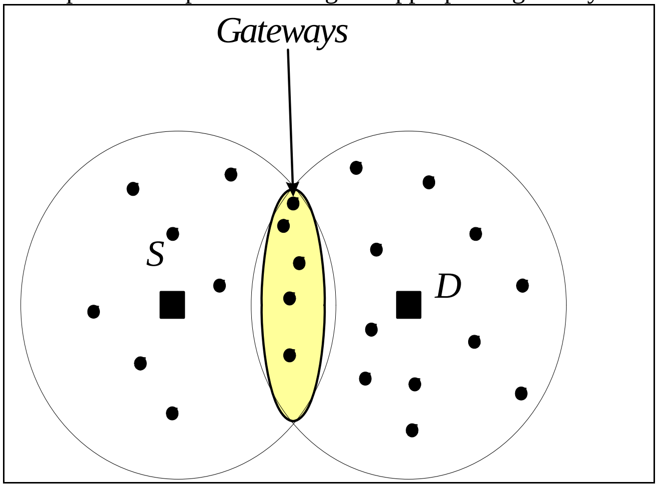

Figure 4: Cluster-based topology

In cluster-based protocols, clusterheads have full knowledge of the networks.

Moreover, in WEAC infrastructure protocol, gateways broadcast their neighbor list, so clusterhead can make the decision to which gateway will route the packet. Nodes other than clusterhead are not required to perform routing. Simply, they forward the packets to their clusterhead and they will take care for the rest. A cluster-based topology is depicted in Fig. 4.

IV. Simulation Model and Performance Metrics

A simulator is developed in order to monitor, observe and measure the performance of the gateways using the deduced formulas from section III using VBS-O/WEAC protocols. The simulation experiments with direct transmission scheme was conducted in a pervious research [15].

The simulator is written using the Java programming language and all the simulation experiments are conducted for ad hoc networks with 25, 50 and 100 mobile terminals. Initially, each mobile station is assigned a unique node ID and a random position in the x-y plane. In this simulation we compare the performance of HEL and LNN schemes and combinations of them by sending packets with maximum transmission scheme and through intermediate nodes.

In the HEL scheme with threshold, we set the threshold as an energy level. If the energy goes below that threshold, then we select the mobile terminal with HEL regardless of the number of neighbors.

In the LNN scheme with threshold, we set the threshold as the number of neighbors. If the number of neighbors goes beyond the threshold then we choose the mobile terminal with HEL.

In the random scheme we choose the gateway randomly.

The simulators measured the following noteworthy statistical performance metrics:

1. The percentage of energy consumed by gateways and their surrounding neighbors using the direct transmission range of mobile nodes (d_{max}) to deliver the packets - The smaller this number, the less energy consumed by gateways and surrounding neighbors. Therefore, optimizing this metric will minimize the power consumption and enlarge the life time of network.
2. The Energy Consumed by Gateways and their surrounding neighbors using intermediate nodes retransmission scheme to send packets rather than direct transmission.
3. The battery power level in each node at the end of simulation using the direct transmission scheme of mobile nodes - This metric shows us how fair the scheme is in balancing the energy consumption through out the network. We calculate the standard-deviation of the energy level of all MTs at the end of the simulation experiments. Therefore, the smaller the difference of energy, the fairer the scheme.
4. The left power in each node at the end of simulation sending packets through intermediate node retransmission scheme.
5. The packet delivery time using the direct transmission scheme of mobile nodes – This metric shows the end to end delay for successful transmitted packets. We calculate the average end to end packet delivery time at the end of the simulation. The smaller this number, the faster the scheme.
6. End-to-end delay sending packets using intermediate nodes retransmission scheme.

The performance metrics are set up for wireless mobile ad hoc networks, which cover a 200 x 200 unit grid. The wireless transmission range of the mobile nodes is 25 units. The velocity of the mobile nodes is uniformly distributed between 0 and 5 units/second, and the nodes are allowed to move randomly in any direction. THRESHOLD_1 is set to 75%, THRESHOLD_2 to 45%, and THRESHOLD_3 to 25% of the maximum power of the battery. The simulation experiments were conducted for 3 simulated hours. 95% confidence intervals have been obtained. Since such intervals are very small, they are not explicitly shown in the performance figures. The comparison was performed by selecting gateways with the Least Number of Neighbors (LNN), the Highest Energy Level (HEL), the HEL with Threshold (HEL with Th), LNN with Threshold (LNN with Th) and the traditional random way of selecting gateways.

Our energy model is based on the results reported in [6] and is shown in Table I below for 2 Mbps wireless NICs. However, unlike the linear model in [9], our study takes into account transmission failures. This is critical to the proper quantification of energy loss in an ad hoc network. Intuitively, idle time will completely dominate system-wide power consumption. The Short Inter-Frame Space, and the Random Backoff time, and DCF Inter-Frame Space are shown in Table II. A sample of the iteration dilation for HCB-model [14] is shown in Table III.

TABLE I
2 MBPS ENERGY FIGURES

Mode	Measurement
Transmit	1.327 W
Receive	966.96 mW
Idle	843 mW

TABLE II
INTER-FRAME SPACES FOR DSSS

Inter-frame Space	Value Used in Simulations (in seconds)
Short Inter-Frame Space (SIFS)	10 μs
Random Backoff Slot	20 μs
DCF Inter-Frame Space (DIFS)	50 μs

TABLE III
ITERATION DILATION HCB MODEL [14]

Algorithm	n = 250, c = 2000, α=2				
	Square Sizes				
	50	300	500	5000	50000
SP Power	1	1.02	1.02	1.05	1.05
Power Progres	1.02	3.96	1.11	1.02	1
I Power Progress	1.03	1.03	1.03	1.03	1.03
Proj. Progress	1.80	1.04	1.13	1	1.03
I Proj. Progress	1.03	1.03	1.03	1.03	2.54
Power	1.03	1.05	1	1.16	1.12
NC	1.15	1.12	1.21	1.26	1.80
SP	2.10	1	1.18	1.13	1.16
Greedy	1.13	1.28	1.28	1.85	2.16

V. SIMULATION RESULTS

Fig. 5 shows the power consumed by gateways and the surrounding affected neighboring nodes using the direct transmission scheme. Surprisingly, there is no big difference in the consumed power between the five schemes.

Hence, there is HEL and LNN scheme did not have a good impact on the network. This is due to the fact that after eventually all the batteries of the nodes will be exhausted (in case of no recharging). Consequently, it does not matter which way we choose, if there no recharge process. The same applies to Fig. 6; there is no noticeable difference in the consumed power between the five schemes. However, in Fig. 5, the performance is better in case of large number of node. In other word, the direct transmission scheme outperforms the intermediate retransmission scheme if the network is denser. If the number of neighbors surrounding the path is low, as in the case of 25 nodes, the intermediate node retransmission scheme has the better performance.

In Fig. 7 and Fig. 8 there is no big difference in power deviation between MTs, the power distribution is balanced among the MTs in the network in both schemes. However, as in Fig. 5 and Fig. 6, using direct transmission scheme out performs the intermediate node retransmission scheme in case of large number of nodes, as in the case of 100 nodes. In Fig. 8, the intermediate node retransmission scheme has the better performance in case of low number of nodes. Fig. 9 and Fig. 10 show that there is no relation between the packet delivery time and method of selecting gateways, HEL or LNN. The difference is negligible. However, there is the performance of the direct transmission scheme is much better than that of the intermediate node retransmission scheme.

VI. CONCLUSIONS

In this paper we have presented a power analysis to estimate the minimum power required for transmission in ad hoc networks. We compared the direct transmission method with the intermediate retransmission method. The simulation results show that the direct transmission scheme, using direct transmission outperforms the intermediate node retransmission scheme if the number of mobile terminals is high. This is because of the fact that, in case of intermediate node retransmission scheme, the network is very populated so the probability that a mobile terminal has neighbors is very high. So each time the packet is propagated all the surrounding neighbors are affected. Nonetheless, the intermediate node retransmission scheme out performs the direct transmission scheme if the number of mobile terminal is low. Direct transmission scheme is very important in case of real time application, where delay is a major factor, such as Voice over IP (VoIP), or video games over IP…etc. Finally, compared five schemes of selecting gateway with direct transmission and intermediate node retransmission, mainly: the Highest Energy Level, the High Energy Level with Threshold, the Least Number of Neighbors, Least Number of Neighbors with Threshold and the Random Schemes, in order to optimize the power consumed by gateways, however, the simulation results show that non of the five scheme is far better than the other. In conclusion, there is more work has to be done in order achieve this goal.

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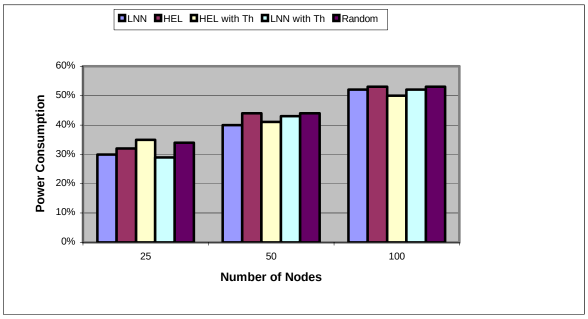

Figure 5: Impact on the network on power consumption by Gateways and their surrounding neighbors using the direct transmission scheme for sending packets

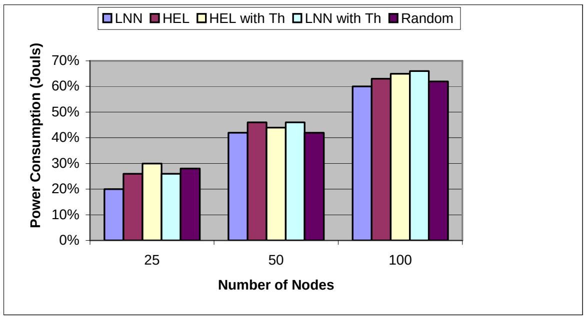

Figure 6: Impact on the network on power consumption by Gateways and their surrounding neighbors using intermediate nodes for retransmitting packets

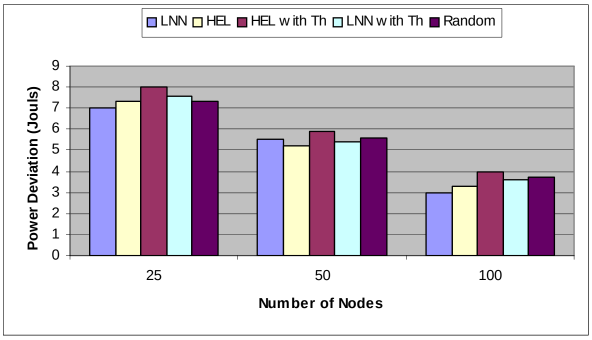

Figure 7: Impact on the network on standard deviation on the power left at the end of the simulation using direct transmission scheme for sending packets

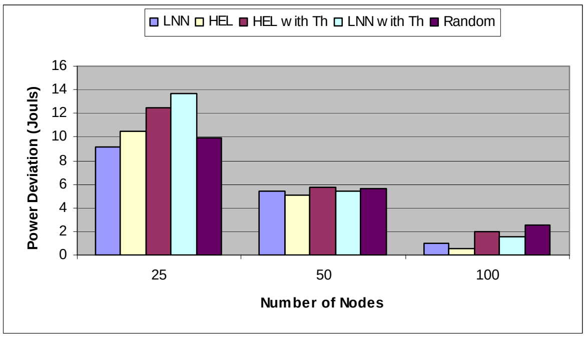

Figure 8: Impact on the network on standard deviation on the power left at the end of the simulation using intermediate node for retransmitting packets

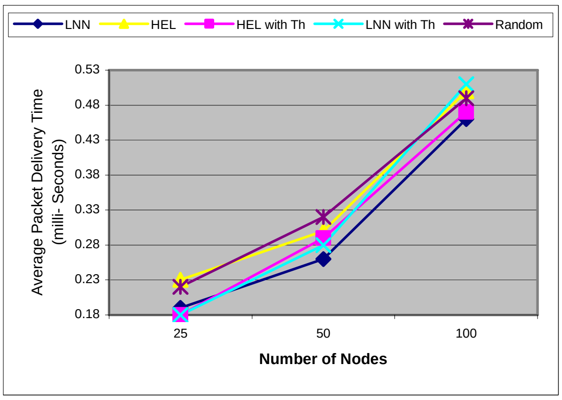

Figure 9: Impact on the network on average end-to-end packet delivery time using direct transmission scheme for sending packets

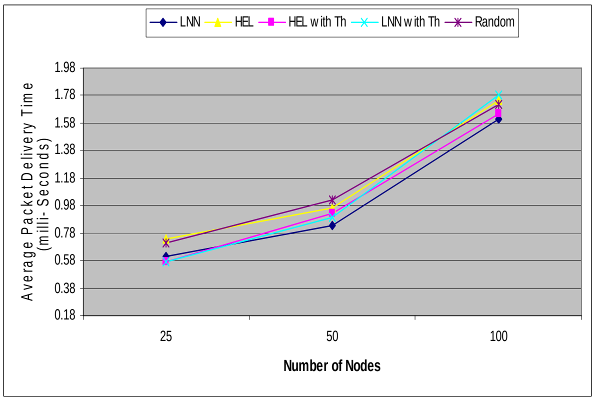

Figure 10: Impact on the network on average end-to-end packet delivery time using intermediate node for retransmitting packets

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Tarek R. Sheltami has received his Ph.D. in Electrical and Computer Engineering from Queen's University, Kingston, Ontario, Canada. He is currently assistant professor at the Computer Engineering Department at King Fahd University of Petroleum and Minerals (KFUPM) Dhahran, Kingdom of Saudi Arabia. He joined the department on September, 2004. Before joining the KFUPM, Dr. Sheltami was a research associate professor at the School of Information Technology and Engineering (SITE), University of Ottawa, Ontario, Canada. He has two years of industrial experience at GamaEng Inc (2002-2004). He is the co-author of the Warning Energy Aware Clusterhead (WEAC) infrastructure protocol and the Virtual Base Station On-demand (VBS-O) routing protocol. Dr. Sheltami has been a member of a technical program and organizing committees of several international IEEE conferences. Dr. Sheltami's research interests are in the area of wireless communications, wireless ad hoc and sensors networks, mobile infrastructure protocols, network control/mobility management, UMTS, and performance evaluation of wireless communication networks.