A Case for Cross Layer Design: The Impact of Physical Layer Properties on Routing Protocol Performance in MANETs

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***Abstract*—In this work we evaluate the performance of routing protocols for mobile ad hoc networks using different physical layer models. The results obtained show that the performance results obtained using idealized models such as the free space propagation model vary significantly when propagation effects such as path loss and shadowing are considered. This difference in performance indicates that optimization is required in the protocol development space that takes into account channel state information (CSI). Such an optimization requires a cross layer approach to be adopted and a framework for protocol performance evaluation to be established. We believe that this work would serve as a first step in this direction. We provide comparative performance results through network simulations.**

Keywords-Ad hoc networks, Cross layer Design, Routing

I. INTRODUCTION

Mobile Adhoc Networks (MANETs) are self-organizing and self-configuring multi-hop wireless networks capable of adaptive re-configuration as effected by node mobility. Typically the network is made up of equal nodes that are equipped for wireless communication and with networking capability. Every node in the network is capable of functioning as a mobile router (i.e., maintain routes & forward packets), which makes possible the multi-hop forwarding of packets from a source node to a destination node without reliance on a fixed infrastructure. All nodes share the same random access wireless channel. With almost all development in information technology being based on wireless technology, ad hoc networks are expected to play a significant role in future communication networks where wireless access to a backbone is either ineffective or impossible.

Routing in MANETs has received significant attention in the research community over the past few years. This has seen the development of several routing protocols. Proactive as well as on-demand routing schemes have been proposed in literature [1]. The performance evaluation of these protocols has invariably focussed on the impact of node mobility on the performance of these protocols. The mobility models used have been varied ranging from individual to group mobility models. Further, each of these performance evaluations has assumed a free space propagation model ignoring the time varying aspects of the wireless channel and its properties such as path loss, multipath fading and shadowing. This is reflected in the assumption a fixed transmission range for each node in the network. In a real world deployment a fixed transmission range is not achievable. As a result the performance of these protocols are less than optimal and do not guarantee the same level of performance in real world deployments.

Next generation networks (3G & beyond) are envisioned to support real time services making use of WLAN, hot spot and ad hoc network technologies. A real-time flow is required to deliver data packets with strict timing requirements. Hence, there is a requirement for optimised routing protocol performance. However, achieving quality of service (QoS) requirements will be impossible if route construction and maintenance procedures do not take into account the time varying characteristics of the wireless channel (such as channel capacity). This optimisation can also be extended to other spheres such as cooperative diversity [2] that can benefit application performance in an opportunistic manner. This is only possible if a cross layer approach is adopted. Cross layer design is best defined as a departure from the reference architecture model that does not allow direct communication between non-adjacent layers or the sharing of variables (e.g., TCP/IP or OSI) [3].

In this work, we do not present an optimised routing protocol using the cross layer approach. Rather, we present a case for such an approach by evaluating the performance of six different ad hoc routing protocols using propagation models that take into account two main characteristics of the wireless channel – path loss and shadowing. We present a comparison between the performance of the protocols in this setting and in the idealised free space propagation setting through network simulations.

In Section II we present a short overview on ad hoc routing protocols. In Section III we present an overview of the propagation models used in our simulations. Section IV details our simulation study and discusses the results with Section V concluding the work.

II. ROUTING IN MANETS

Routing in ad hoc networks faces extreme challenges from node mobility/dynamics, potentially very large number of nodes and limited communication resources (e.g., bandwidth and energy)[1]. This has prompted significant research in this domain. In this section we present a high level view of six routing protocols. The reader is directed to the specific literature for a more in depth treatment.

A. *Ad Hoc On Demand Distance Vector (AODV)*

AODV [4] is classified as a pure on-demand route acquisition system since nodes that are not on a selected path do not maintain any routing information or participate in routing table exchanges. AODV typically reduces the number of required updates by creating routes on-demand as opposed to maintaining a complete list of routes to all destinations. In AODV when a route to a destination is required and a valid route is not available, a route discovery process is initiated. The source broadcasts its request to its neighbours who in turn forward it to their neighbours and so on. To reduce the route discovery overhead the request is dropped if an intermediate node that receives the request has a valid route to the destination. If not the request propagates until the destination is reached.

AODV employs backward learning (i.e., on receiving a request the transit nodes learn the path to the source), which enables the destination to send the route request reply along the path taken by the query. The intermediate nodes that receive the route reply set up active forward routes in their routing tables that point to the node that generated the route reply. This path of active forward routes becomes the route that is employed. Once a route has been chosen it is maintained as long as it is in use by the source. A link-failure or topology change is reported recursively through all intermediate nodes to the source, which triggers another route discovery process to identify an alternate route.

B. *Dynamic Source Routing(DSR)*

DSR [5] is on-demand routing protocol that is source-initiated. The sender explicitly lists the route in the packet's header, identifying each forwarding "hop" by the address of the next node to which to transmit the packet on its way to the destination host. The DSR protocol consists of two mechanisms: Route Discovery and Route Maintenance.

In DSR each node receiving a route request checks its cache to see if it possesses a valid route to the destination. If not it adds its own address to the route record of the request packet before forwarding. A route reply message is initiated in response to a route request by either the destination node or an intermediate node that has a valid route to the destination. In the route reply message the destination node provides the source with the route record from its corresponding route request. The route reply message can be returned either by source routing from the destination node back to the source node or by route reversal in the case of symmetric links being used. Otherwise a route discovery process for the route reply message is to be initiated. In the event of link failure, route reconstruction can be delayed if the source has an alternate route to the destination. If not route discovery would need to be initiated. The overhead of the route discovery process increases linearly with the number of nodes in the network.

C. *Location Aided Routing (LAR)*

Location Aided Routing (LAR) [6] is an on-demand protocol based on source routing. The protocol uses location information to define the Expected Zone and the Request Zone to aid in route discovery and in limiting the flooding area. LAR performs route discovery through limited flooding - reducing the number of route request messages. The expected zone of a node D with respect to a node S is the region in which node S expects to find node D at a time t_1. This can be calculated if the location L of node D at time t_0 and its average speed v are known. The expected area is the circle of radius $v(t_1-t_0)$ centred at L. If node S is not aware of the previous location of D then the entire region of the ad hoc network is considered to be the expected zone. The request zone is defined so that a node forwards the route request only if it belongs to the request zone. The request zone must include the expected zone to ensure that the request would reach the destination. In some cases when S is outside the expected zone it is necessary to include areas outside the expected zone. S and D must both belong to the request zone. If a path cannot be found within a predefined time period then the entire network space is included in the following route request. The probability of finding a path increases as the request area increases. However the route discovery overhead also increases with the size of the request zone. In LAR scheme 1, the request zone is defined as the smallest rectangle that contains the current location of the source and the expected zone of the destination such that the sides of the rectangle are parallel to the co-ordinate axes. The source node determines the four corners of the rectangle and includes their co-ordinates in the route request message. A receiving node is thus able to determine if it is in the request zone and forwards or discards the route request accordingly.

D. *Landmark Adhoc Routing Protocol (LANMAR)*

LANMAR [7] has been proposed for large scale ad hoc networks that exhibit group mobility characteristics.

If there exists a commonality of interest then the nodes of the ad hoc network will move as a group (e.g., battalions in military situations). In that case it is possible to identify logical subnets. Each logical subnet elects one of its nodes to act as a landmark and these are used to keep track of each subnet. Routing information regarding all landmarks is propagated by a distance vector scheme such as DSDV [8]. LANMAR also incorporates a local scope routing scheme for routing within a given scope D for a node. Each node has detailed topology information about nodes within its local scope and a distance and routing vector to all landmarks. When the destination is within the local scope then the FSR [9] routing tables are used. If the destination is outside the scope then the packet is routed to the destination landmark. Once the packet arrives within the scope of the destination then routing using the FSR routing information is resumed. LANMAR employs an IP like address consisting of group-ID (subnet ID) and a host ID <GroupID, HostID> to identify each node. LANMAR reduces both routing table size and control overhead effectively through the localized routing table and grouped routing table for remote destinations.

E. *Fisheye State Routing (FSR)*

FSR [9] is a link state (LS) type proactive protocol employing a flat view of the network topology.

FSR maintains topology information at each node and propagates periodical link state updates to its neighbours. The LS information is not flooded to the entire network. The exchange of link state information is periodic rather than event-driven, which avoids frequent link updates in an environment of unreliable wireless links and high mobility. Broadcast of routing information is scaled with reference to the distance to the destination. Update of routes to closer destinations is more frequent than updates for routes to distant destinations. FSR provides precise and efficient routing to the immediate neighbourhood but increases in imprecision to distant destinations.

F. *Zone Routing Protocol (ZRP)*

ZRP [10] is a hybrid routing protocol that employs both proactive and on-demand routing strategies and aims to combine the advantages of both. Each node in the network defines a zone centred on itself in terms of number of hops. For every destination that is within the zone the node maintains proactive routing information while for destinations outside the zone no routing information is maintained. When an inter-zone connection is required an on-demand routing strategy is employed. The protocol essentially is made up of the proactive Intra-zone Routing Protocol (IARP) and the on-demand Inter-zone Routing Protocol (IERP). IARP can be any LS or distance vector routing protocol. IERP uses route discovery mechanisms similar to an on-demand routing protocol. When a route to a destination is not known (i.e., the destination is not within the zone) IERP broadcasts a route request from the border nodes of its zone. Route requests are broadcast only from one node's border nodes to the other border nodes until a route is found for the intended destination (i.e., a node whose zone contains the destination). The Bordercast Resolution Protocol (BRP) [11] is employed for this type of route request broadcast. The hybrid scheme limits the on-demand route request overhead to only selected border nodes.

III. PATH LOSS AND SHADOWING

The aim of a propagation model is to predict the received signal power of each packet. The received signal power impacts on the ability of the receiver to decode the received packet and is dependent on the path loss that is experienced as well as other effects of the wireless channel such as shadowing and fading. For an accurate estimate of the path loss that is experienced various models including empirical models have been proposed [13]. We present the two path loss models that are used in our simulations. Further we also present two shadowing models that are used – lognormal shadowing and constant shadowing. Free space propagation models assume zero shadowing.

A. *Free Space Propagation*

The free space model [12] represents the communication range as an imaginary circle around the transmitter. If a receiver is within the circle, it receives all packets; otherwise, it loses all packets. This model is mostly used when a MANET is employed in an open-field like environment.

The free space propagation model assumes the ideal propagation condition, where there is only one clear line-of-sight path between the transmitter and the receiver. The transmission loss is due to the propagation distance only. Giving a distance d between the transmitter and the receiver, the received signal power $P_r(d)$ is given according to Friis free-space equation

$$P_r(d)=\frac{P_t\cdot G_t\cdot G_r\cdot\lambda^2}{(4\pi\cdot d)^2\cdot L}$$

, where P_t is the transmitted signal power, G_t and G_r are the antenna power gain of the transmitter and of the receiver respectively, a constant L is the system loss and λ is the wavelength. So, the path loss is

$$PL(d)=-10\log_{10}\left(\frac{P_r}{P_t}\right)=20\log_{10}\left(\frac{4\pi d}{\lambda}\right)+C$$

, where C is a constant.

B. *Two Ray Ground Reflection*

The two-ray ground reflection model [12] considers both the direct path and a ground reflection path, when a single line-of-sight path between two nodes is accurate enough. At a long distance, the two-ray ground reflection model will give more accurate prediction than the free space model. The received power at distance d is

$$P_r(d)=\frac{P_t\cdot G_t\cdot G_r\cdot h_t^2\cdot h_r^2}{d^4}$$

, where h_t and h_r are the heights of the transmitter's and the receiver's antenna respectively. This equation indicates a faster power loss than the free space propagation model, when the distance increases. The two-ray ground reflection model works better when d > $4\pi h_t h_r/\lambda$. The path loss is

$$PL(d)=-10\log_{10}\left(\frac{P_r}{P_t}\right)=20\log_{10}\left(\frac{d^2}{h_t\cdot h_r}\right)+C$$

, where C is a constant.

C. *Constant Shadowing*

The free space model and the two-ray ground reflection model treat the received power as a deterministic function of distance, and treat the transmission range as an ideal circle. In fact, the received power at certain distance is a random variable rather than a constant. On the other hand, the constant and the lognormal shadowing models extend the ideal circle model to a statistic model: Mobile nodes can only probabilistically communicate when they are near the edge of the communication range.

The constant shadowing model [12] is a path loss model similar to the free space model and the two-ray ground reflection model, which also predicts the mean received power at distance d denoted by $P_r(d)$. It uses a close-in distance d_0 as a reference point. $P_r(d)$ is calculated as

$$\frac{P_r(d_0)}{P_r(d)} = \left(\frac{d}{d_0}\right)^{\beta}$$

, where $P_r(d_0)$ is obtained by following the free space model and β is called the path loss exponent. The path loss exponent β is usually empirically determined by field measurement – larger values correspond to more obstructions and hence faster decrease in average received power as distance becomes larger. In addition to the path loss $PL(d_0)$ of non-shadowing models, the new path loss becomes

$$PL(d) = -10\log_{10}\left(\frac{P_r}{P_t}\right) = -10\log_{10}\left(\left(\frac{d_0}{d}\right)^{\beta} \cdot \frac{P_r(d_0)}{P_t}\right) =$$

$$-10\beta\log_{10}\left(\frac{d_0}{d}\right) + PL(d_0)$$

D. Lognormal Shadowing

The lognormal shadowing model [12] takes account in the variation of the received power at certain distance. The variation is a lognormal random variable, and is of Gaussian distribution. The path loss of the lognormal shadowing model is described based on the constant shadowing model as

$$PL(d) = -10\beta\log\left(\frac{d_0}{d}\right) + PL(d_0) + X_{dB}$$

, where X_{dB} is is a Gaussian random variable with zero mean and a standard deviation σ_{dB}. And σ_{dB} is called the shadowing deviation and is obtained by field measurement similar to β.

IV. Simulation Study

We performed simulation study of the routing protocols making use of the Qualnet 3.9.5 simulation tool. The simulation environment consisted of a mobile ad hoc network of 50 nodes in a network area of 1500m by 1500m. The network layout followed a random deployment to simulate a real world deployment and each node was capable of movement from its initial position following the random waypoint mobility model [1]. We simulated six different scenarios using a combination of the two path loss models (free space and two ray ground reflection) and three shadowing models (none, constant and lognormal). The idealised scenario is the free space model with the shadowing model set as 'none'. In each scenario we simulated four Constant Bit Rate (CBR) sources that generated traffic to a specific destination with a mean interval of 1sec and a packet size of 500bytes. Each simulation run was for 30 secs and the results presented are averaged over 20 simulation runs with random seed values. Our metrics of interest were the average throughput (bits/sec), average end to end delay (sec) and average jitter (sec) calculated at the destinations. All calculations are done at the application layer.

To illustrate the impact of path loss and shadowing on routing protocol performance we plot the 3 metrics of interest for AODV in Figures 1-3. Results for the other protocols are presented in Table 1. In Figure 1, we see the throughput observed across the network for the six scenarios. As expected the ideal model (free space with no shadowing) gives us the best performance. In the free space propagation model assuming a circular static communication range the average throughput observed is more than 4000 bits/sec.

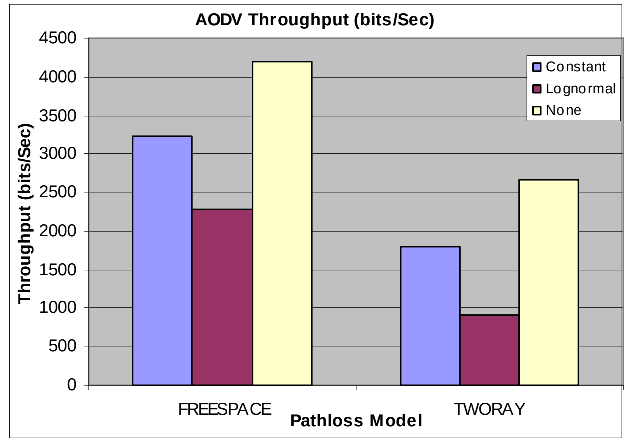

Figure 1. AODV variation in throughput

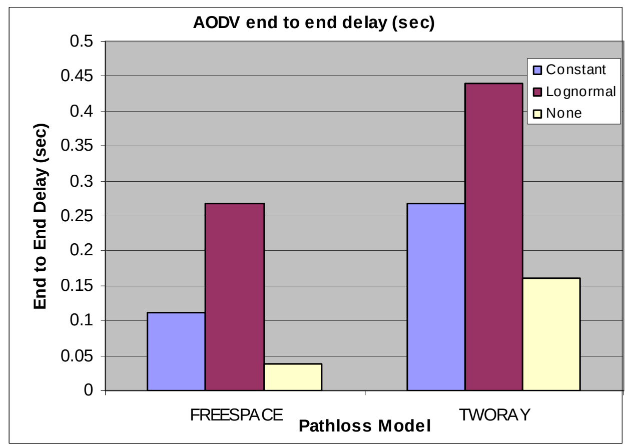

Figure 2. AODV variation in end to end delay

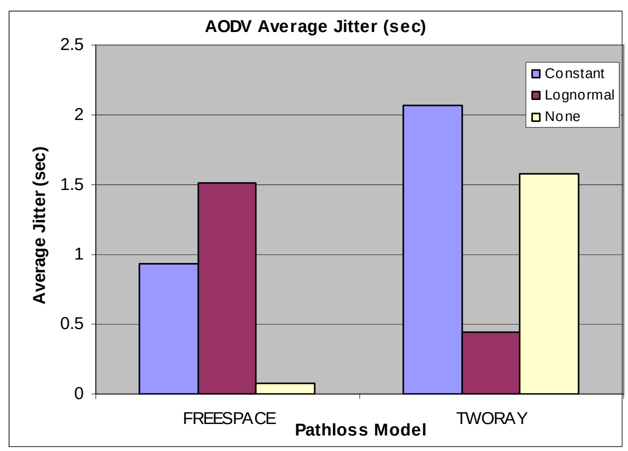

Figure 3. AODVvariation in jitter

TABLE I. PROTOCOL PERFORMANCE

Protocol	Path Loss	Shadowing	T/put (bits/sec)	Delay (sec)	Jitter (sec)
DSR	Free Space	Constant	4368	0.1120	0.9273
		Lognormal	4342	0.0543	0.0528
		None	4338	0.0493	0.0486
	Two Ray	Constant	4289	0.1159	0.0927
		Lognormal	4357	0.1179	0.0945
		None	4332	0.0818	0.0558
LANMAR	Free Space	Constant	2142	0.0655	0.0655
		Lognormal	2357	0.0708	1.4040
		None	3582	0.0434	0.3680
	Two Ray	Constant	1627	0.0641	1.6922
		Lognormal	891	0.0538	1.0821
		None	2221	0.0626	1.3428
LAR	Free Space	Constant	4096	0.2139	1.4888
		Lognormal	4375	1.4679	1.3337
		None	4418	0.1303	0.0925
	Two Ray	Constant	3821	0.6334	0.7904
		Lognormal	5087	3.3087	2.0168
		None	4064	0.2644	0.4426
FSR	Free Space	Constant	2614	0.0912	0.7806
		Lognormal	1493	0.0961	2.1641
		None	3689	0.1354	0.5415
	Two Ray	Constant	753	0.0133	0.1973
		Lognormal	318	0.0314	0.2749
		None	2517	0.0517	0.1678
ZRP	Free Space	Constant	2464	0.0938	0.8541
		Lognormal	1491	0.0932	2.0171
		None	3191	0.0572	0.4178
	Two Ray	Constant	2826	0.0636	0.4713
		Lognormal	1006	0.1482	1.9275
		None	2988	0.0869	0.7029

Compared to this ideal scenario the results obtained in the free space propagation scenario with constant and lognormal shadowing effects are significantly lower (around 3200 bits/sec and 2300 bits/sec respectively). There is almost a 50% difference in performance between the ideal scenario and the free space with lognormal shadowing model. A similar trend is observed using the two-ray ground reflection model as well. The difference between the ideal scenario and the worst case scenario (Two Ray with lognormal shadowing) is more than 70%. This drastic reduction in performance does not bode well for the scheme in real world deployments. Similar trends are observed across all protocols and across the three metrics (with some exceptions). Further these results are without including additional factors that will affect the quality of the signal that is received such as fading effects and weather conditions. It is our observation that the main reason for this drastic difference in performance is the use of inefficient path metrics (such as hop count or distance) in the calculation of best routes to a certain destination. A drawback of most routing protocols is their failure to take into account the current quality of a link during the route construction phase. The time varying nature of the channel and the asymmetric nature of links make this a non-trivial problem. Further, in energy constrained networks such as MANETs and sensor networks, the residual energy available in each node needs to be considered and included in the path metric value.

V. CONCLUSIONS AND FUTURE WORK

In this work we have presented a need for routing protocol designers to take into account the physical characteristics of the channel during the route construction phase. Our simulation results prove that the performance obtained when physical layer properties such as path loss and shadowing are considered is drastically different in comparison to the ideal scenario. This requires path metrics that take into account CSI to be developed and included in well established routing protocols for all practical purposes. In our future work we will extend this study to include other factors such as channel fading. We will use the Rayleigh and Ricean fading models for this purpose. Further we hope to develop an efficient path metric that takes into account the current state of the channel and the quality of the link. We also hope to explore opportunistic routing strategies that a cross layer approach can make possible.

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