A Connection Management Protocol to Support Multimedia Traffic in Ad Hoc Wireless Networks with Directional Antenna

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ABSTRACT

Use of directional antenna in the context of ad hoc wireless networks can drastically improve the medium utilization through overlapping communications in different directions. However, all the existing routing schemes proposed in this context rely on the use of omni-directional antenna. The use of directional antenna to find out a route and use it in data communication has not been explored properly. We have proposed a modified link-state based table-driven routing protocol that captures the approximate network status periodically without generating lot of control traffic and makes all nodes in the system *topology-aware*. It uses the directional capability of adaptive antenna for capturing, disseminating and using the network information for directional routing. Additionally, we have attempted to address the issue of managing an uninterrupted connection between a source and a destination over adaptively selected routes in temporal domain. The protocol enables each node to constantly evaluate network conditions and to take decisions on adaptive route selection.

1. INTRODUCTION

Recently, there is a growing interest in ad hoc networks and its applications [1]. We are working towards implementing Wireless Ad Hoc Community Network (WACNet) that uses small, low-cost directional antenna, known as ESPAR (Electronically Steerable Passive Array Radiator) antenna, with each user terminal [2,3]. We have proposed an adaptive MAC protocol in the context of WACNet in our earlier work [4]. The objective of this paper is to illustrate the directional routing protocol and a connection management scheme between source and destination for multimedia data communication in the context of WACNet.

The dynamics of wireless ad hoc networks as a consequence of mobility and disconnection of mobile hosts pose a number of problems in designing proper routing schemes for effective communication between any source and destination [1]. Several researchers feel that on-demand, reactive routing schemes that do not use periodic message of any kind would be more suitable in the context of ad hoc networks. However, it has been observed that these protocols perform well under light traffic and low mobility, but performance degrades significantly under high mobility and high traffic load [5,6]. As mobility increases, the pre-computed route may break down, requiring multiple route discoveries on the way to destination. Route caching becomes ineffective in high mobility. Stability-based routing schemes [6] that tend to evaluate the life-span of a path reduces this problem, but can not eliminate it. Moreover, since flooding is used for query dissemination and route maintenance, on-demand routing tends to become inefficient when the frequency of communication requirement is high. On the other hand, several researchers have proposed proactive routing schemes based on classical distance vector or link-state routing [1]. Unfortunately, as these schemes rely on flooding of routing updates, excessive control overhead may be generated, especially in a highly mobile environment. Thus, in the context of ad hoc networks, researchers have focused on restricting the propagation of routing updates, thereby reducing the control overheads. For example, Optimized Link State Routing (OLSR) protocol [7] is an optimization of the pure link state algorithm tailored to the requirements of a mobile wireless LAN. Fisheye State Routing (FSR) [8] introduces the notion of multi-level fisheye scope to reduce routing update overhead in large networks.

Whatever may be the routing scheme, they all rely on using omni-directional antenna. The use of directional antenna to find out a route and use it in data communication has not been explored properly. In our earlier work [4], we have proposed an adaptive MAC protocol, where each node keeps certain neighborhood information dynamically through the maintenance of an Angle-SINR Table in order that each node knows the direction of communication events going on in its neighborhood at that instant of time. Moreover, appropriate mechanism for null steering of directional antennas in user terminals can help exchanging the neighborhood information in presence of on-going communication and can improve the medium utilization drastically through overlapping communications in different directions. In this paper, we will show that the Angle-SINR table helps us to implement directional routing, since it helps each node to determine the best possible direction of communication with any of its neighbor. We have proposed a modified link-state based table-driven routing protocol that captures the approximate network status periodically without generating lot of control traffic. It uses the directional capability of adaptive antenna for capturing, disseminating and using the network information for directional routing. This will make each node in the system topology-aware. As a consequence of topology-awareness, we have attempted to address the issue of managing an uninterrupted connection between a source and a destination over adaptively selected routes in temporal domain. The protocol enables each node to constantly evaluate network conditions and to take decisions on adaptive route selection. This would enable a node to transfer multimedia data without interruption.

2. THE FRAMEWORK

2.1 Angle-SINR Table

In order to make the directional routing effective, a node should know how to set its transmission direction effectively to transmit a packet to its neighbors. So, each node periodically collects its neighborhood information and forms an Angle-SINR Table (AST). $SINR^{u}_{n,m}(t)$ (Signal -to- Interference and Noise Ratio) is a number associated with each link $l^{u}_{n,m,}$ and is a measurable indicator of the strength of radio connection from node n to node m at an angle u with respect to n and as perceived by m at any point of time t. AST of node n specifies the strength of radio connection of its neighbors with respect to n at a particular direction. Angle-SINR Table for Node n at time t is shown below (Table I) where we assume that nodes i, j and k are the neighbors of n.

TABLE I. ANGLE-SINR TABLE (AST) FOR NODE n

Azimuth Angle (degree)	SINR value as perceived by neighbors of node n at different angle w.r.t node n		
	i	j	k
0	$\mathbf{SINR^{0}_{n,i}}$ (t)	$\mathbf{SINR^{0}_{n,j}}$ (t)	$\mathbf{SINR^{0}_{n,k}}$ (t)
30	$\mathbf{SINR^{30}_{n,i}}$ (t)	$\mathbf{SINR^{30}_{n,j}}$ (t)	$\mathbf{SINR^{30}_{n,k}}$ (t)
60	$\mathbf{SINR^{60}_{n,i}}$ (t)	$\mathbf{SINR^{60}_{n,j}}$ (t)	$\mathbf{SINR^{60}_{n,k}}$ (t)
…..	…..	…..	…..
330	$\mathbf{SINR^{330}_{n,i}}$ (t)	$\mathbf{SINR^{330}_{n,j}}$ (t)	$\mathbf{SINR^{330}_{n,k}}$ (t)

In order to form AST, each node periodically sends a directional request in the form of a directional broadcast, sequentially in all direction. In this work, it has been done at 30 degree interval, covering the entire 360 degree space sequentially. A node i in the neighborhood of n will wait until it receives all the request packets generated by n in all direction at that occasion. In other word, node i accumulates the entire column of the AST of n for node i. Here, node i, after receiving the first request from n, has to wait a pre-specified amount of time to make sure that the directional broadcasts by n in all direction are over. Node i sends this information to node n as a data packet. After receiving this information from all the neighbors of n, the Angle-SINR Table of n would be complete.

2.2 Neighborhood-Link-State Table

Affinity of node m with respect to node n, $a^{w}_{n,m}(t)$, is a non-negative number associated with a link $l^{w}_{n,m}$ at time t , such that $a^{w}_{n,m}(t)$ = Max [$SINR^{u}_{n,m}(t)$, 0< u <360]. In other words, the transmission angle w with respect to n maximizes the strength of radio connection from n to m, as perceived by m at any point of time. This maximum SINR value is affinity of m with respect to n and this is obtainable when the antenna at n is directed towards m at an angle w with respect to n. Based on this, a Neighborhood-Link-State Table (NLST) at each node is formed as shown below (Table II). The NLST of node n, at any instant of time, will help us to determine the best possible direction of communication with any of its neighbor. This information will be helpful in realizing both adaptive MAC protocol and directional routing protocol.

TABLE II. NLST AT NODE n

Neighbors of n	Affinity
i	Max [$SINR^{u}_{n,i}(t)$, 0< u<360]
j	Max [$SINR^{u}_{n,j}(t)$, 0< u <360]
k	Max [$SINR^{u}_{n,k}(t)$, 0< u <360]

3. DIRECTIONAL ROUTING

3.1 Basic Mechanism

We have designed a modified link-state protocol to make the nodes in the network **topology aware**. Our primary aim is to collect all topology-related information from each node in the network and distribute them periodically (as updates) to only one of its neighbor, without flooding the network with topology-update packets. A node maintains a complete (but approximate) topology map of the entire network, called Global Link State Table(GLST). It not only depicts the connectivity between any two nodes but also the strength of connection or **affinity** value of the connection. This link-metric will help us to determine a stable route [6] as defined as follows:

Path Stability: Given a path p = (i, j, k, …, l, m), **Path Stability** of p, $\eta^{p}_{sd}(t)$, at some instant of time t from source s to destination d will be determined by the lowest-affinity link in the path (since this is the bottleneck for the path), is given by: $\eta^{p}_{sd}(t) = \min [a^{\theta}_{i,j}(t)], \forall i,j \in p$.

Once the routes are determined, MAC layer will take care of the communication direction based on NLST stored at each node.

In order to use the directional antenna, a node propagates its perception of the topology-information to only one of its neighbors at a periodic interval. Selection of target neighbor to propagate topology-map based on a criterion termed as least-visited-neighbor-first. Each node monitor a metric called recency of its neighbors to decide which of them has received least number of update messages. The neighboring node that has received least number of update messages so far will be the target node for updating. This criteria and some related additional criteria to maintain the homogeneity of topology-update-packets propagation will be discussed later.

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 nods in the system. However with periodic update messages from its neighbors about their neighbors, the nodes slowly get information about the other nodes and their neighbors. It is to be noted that by controlling the periodicity of updates (P_T), it is possible to control the topology-update-traffic in the network and the accuracy of topology map stored in each of the node. For example, if the propagation of update messages is too frequent, the control traffic will increase but the accuracy of topology map stored in each node will also be better. However, the topology-update packet would always migrate from a node to only one of its neighbor after a periodic interval P_T using directional antenna. Moreover, it is periodic in nature. So, the network would never get flooded with propagation of topology updates. The total number of update packets moving around the network will be equal to the number of nodes in the network.

A major aspect underlying the infiltration of topology information into mobile nodes is that the information carried must be recognized with a degree of correctness. Since the propagation of topology updates from different nodes is asynchronous, it becomes imperative to introduce a concept of recency of information. For example, let us assume two update packets A_1 and A_2 arrive at node n, both of them carrying information about node m which is multi-hop away from node n. In order to update the topology information at node n about node m, there has to be a mechanism to find out who carries the most recent information about node m : A_1 or A_2 ?

To implement that, every node in the network has a counter that is initialized to 0. When a topology-update-packet leaves a node, it increments that counter by one. We term this counter as recency token. The topology-update-packet while leaving a node stores the new value of the incremented recency token against the node's ID within its data structures. Thus at any point of time, the magnitude of the recency token of any node represents the number of times that node has been updated since the commencement of the network. This also implies that if two update-packets have a set of data concerning the same node, say node n, then the update-packet carrying the higher recency token value of node n has more current information about it.

The concept is similar to DSDV [1] where the distance are updated according to the time-stamp or sequence number assigned by the node originating the update. However, the recency token has another role to play. Any node, say n, selects a target neighbor to propagate topology-update-packet based on the value of recency of its neighbors. The value of recency would help the node n to decide which of its neighbors has received least number of update messages. The neighboring node that has received least number of update messages so far, i.e. having lowest value of recency token, will be the target node for updating.

We have developed a metrics, average node-affinity convergence [9], to quantify the deviation of actual network topology with the network topology perceived by individual nodes at any instant of time. It is to be noted that this metric is used for performance evaluation only using an off-line algorithm to determine this deviation from the actual network topology.

Let α^a_{nm} be the affinity between node n and m as perceived by node a at any instant of time and α_{nm} is the actual affinity between node m and n at that instant of time. Information about link status α^a_{mn} is said to converge at node a iff $\alpha^a_{mn} <= \alpha_{mn}$. As indicated earlier, affinity is a worst-case prediction about strength of connection between two nodes. So, if the affinity of a link between n and m as perceived by a node a is less than actual affinity between n and m, we will accept this as a worst-case perception of node a about the node-affinity between n and m. However, if $\alpha^a_{mn} > \alpha_{mn}$, we will consider this as an overestimate by node a about the node- affinity between n and m and we reject the perception.

Thus, **node-affinity convergence** of link between n and m at node a, $\lambda^a_{nm} = 1$, if $\alpha^a_{mn} <= \alpha_{mn}$ and 0 otherwise.

node-affinity convergence of node a, λ^a , for all links in the network, is defined as:

$\lambda^a = (\Sigma_{\text{for all node-pairs i-j}} (\lambda^a_{ij}))$ / total number of node-pairs

At some instant of time, if $\lambda^a = 1.0$, it implies that the topology information at node a is 100% acceptable, so far as affinity-based prediction mechanism is concerned.

The **average node-affinity convergence,** $\lambda_{avg} = (\Sigma_{\text{for all nodes k}} (\lambda^k))$ / number of nodes

The Node-Affinity convergence graphs shown in figure 1 show satisfying results, as the curve always remains above 98 percent after the topology information has stabilized. This means, the node-affinity information that any node knows about a path is acceptable to the extent of 98%.

3.2 Uninterrupted Connection Management

We are now in a position in which each of the nodes has a local view of the network topology i.e. each node is topology aware. This leads to a scenario where conventional route discovery is no longer necessary. More explicitly, the nodes can now determine the most stable route locally and initiate the sending of data packets through it. After a point of time, if the source node finds that the chosen route has attained a low stability (indicating that it would soon cease to exist), the node computes a new, more stable route from the local information cache and redirects data packets through the later. This adaptive route selection facilitates continuous communication through multiple paths in the temporal domain. Thus we can envision that as long as two nodes remain connected, they will always be able to get at least one route through which communication can continue. In the case of multi-route availability, the best route can always be selected. Quite perceivably, the adaptive selection of best routes guarantees an uninterrupted communication session between two nodes thus ensuring multimedia data transfer to occur.

The success of the scheme relies on the fact that nodes s and d are always connected through some intermediate nodes in spite of mobility. In other words, the intermediate nodes through which s-d are connected may change with time, but s-d should remain connected. In Figure 2, we have shown the stability of most stable path between two arbitrary nodes 14 and 5, sampled at each 5-second interval of time. As shown in the figure, it has been observed that no single path is stable throughout the span of 30 sec. However, we are getting a sustained stability between node 14 and 5 through different intermediate nodes. This establishes the viability of our scheme. In other words, if a source node evaluates the route to destination from its locally – stored topology map, it is possible to find out a series of multiple paths in temporal domain to complete a large volume of data transfer without interruption.

4. SUMMARY

In order to support real time/multimedia communication, the two important factors are: uninterrupted communication and delay minimization. Our technique ensures that, in a dynamic but connected network, two nodes can choose to maintain an uninterrupted communication session for an indefinite span of time, unless the network gets partitioned. This means that a huge stream of data could be packet-switched, with the stream flowing through adaptively selected routes at the source node. Thus what seems to be a free flowing stream of continuous data packets is actually an outcome of zero-latency, periodic route computation, performed locally and almost parallel with message transfer. Another issue of relevance in this mechanism is that, in transporting data from a source to a destination, a route is used only for that span of time for which it is perceived to be the best route. This implies that no path is held indefinitely, causing the network resources to be shared amongst the prospective claimants. The introduction of link load (besides stability) as one of the other parameters to determine best route will take care of automatic load balancing in the system. In other words, a less loaded links could be marked, compelling the source to choose this link and thus distributing the load from previously loaded ones.

5. REFERENCES

[1] E. M. Royer and C-K Toh, "A Review of Current Routing Protocols for Ad hoc Wireless Networks", IEEE Personal Communication, April 1999, pp. 46-55.

[2] M. Kawai, M.Nozaki and K.Gyoda, "A wireless Ad Hoc Community Network with Reconfigurable Topology Architecture", Proc. Of the GLOBECOMM'98, 1998.

[3] T. Ohira and K.Gyoda, "Electronically Steerable Passive Array Radiator (ESPAR) Antennas for Low-cost Adaptive Beam forming", IEEE International Conference on Phased Array Systems, Dana Point, CA May 2000.

[4] S.Bandyopadhyay, K.Gyoda, K.Hasuike, S.Horisawa, Y.Kado and S.Tawara, "An Adaptive MAC Protocol for Wireless Ad Hoc Community Network (WACNet) Using Electronically Steerable Passive Array Radiator Antenna", submitted to GLOBECOM 2001.

[5] S R Das, Charles Perkins and Elizabeth Royer, "Performance Comparison of Two On-demand Routing Protocols for Ad Hoc Networks", Proc. Of the IEEE INFOCOM 2000, Tel-Aviv, 26-30 March, 2000.

[6] Krishna Paul, S. Bandyopadhyay, D. Saha and A. Mukherjee, "A Stability-based Distributed Routing Mechanism to Support Unicast and Multicast Routing in Ad Hoc Wireless Network", to appear in Computer Communications, Elsevier Press.

[7] Amir Qayyum, Philippe Jacquet, Paul Muhlethaler, "Optimized Link State Routing Protocol". http:// www.ietf.org/ internet-drafts/ draft-ietf-manet-olsr-01.txt,Feb 2000. IETF Internet Draft (work in progress).

[8] Guangyu Pei, Mario Gerla and Tsu-Wei Chen, "Fisheye State Routing: A Routing Scheme for Ad Hoc Wireless Networks" in Proc of the IEEE International Conference on Communication, New Orleans, LA, June 2000.

[9] Romit RoyChouldhury, S. Bandyopadhyay and Krishna Paul, "Topology Discovery in Ad Hoc Wireless Networks Using Mobile Agents", Proc, of the Second International Workshop on Mobile Agents for Telecommunication Applications, Paris, France, September 18-20, 2000.

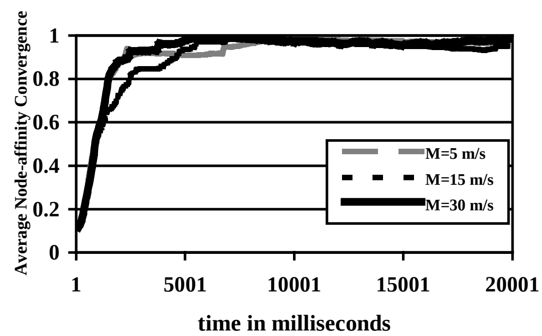

Fig.1 Node-affinity convergence vs. time at a periodicity of update of 100 msec.

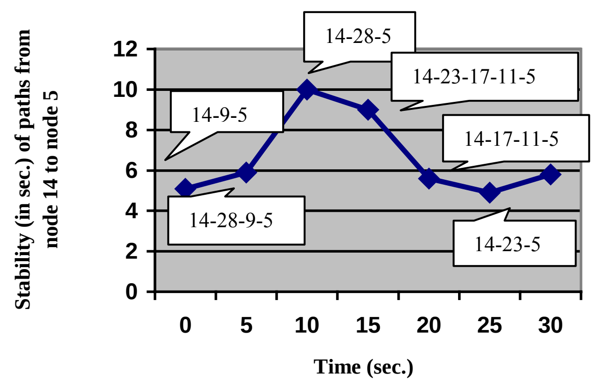

Fig 2. Stability of maximum stable path between node 14 and 5, sampled at each 5-second interval of time (the path is given in the boxes).