ACR: An Adaptive Communication-Aware Routing through Maximally Zone-Disjoint Shortest Paths in Ad Hoc Wireless Networks with Directional Antenna

Tetsuro Ueda*, Shinsuke Tanaka, Bokuji Komiyama
ATR Adaptive Communication Research Laboratories
2-2-2 Hikaridai, Seika-cho Soraku-gun, Kyoto 619-0288 JAPAN
e-mail: {teueda, shinsuke, komiyama}@atr.jp
Tel: +81-774-95-1529
Fax: +81-774-95-1509

Siuli Roy, Dola Saha, Somprakash Bandyopadhyay
Indian Institute of Management Calcutta
Diamond Harbour Road, Joka
Calcutta 700104
India
e-mail: {siuli, dola, somprakash}@iimcal.ac.in
Tel: +91-33-2467-8300
Fax: +91-33-2467-8062

Summary

A fundamental problem that distinguishes wireless networks from wired networks is the mutual interference between routes within the proximity of each other. This phenomenon is known as route coupling and it restricts the possibility of occurrence of simultaneous communications along the coupled routes. In this context, the use of directional antenna, having smaller transmission beam-width compared to omni-directional antenna, helps to easily decouple interfering routes, and improves network performance through Space Division Multiple Access (SDMA). However, even if we have an efficient directional MAC protocol, it alone would not be able to guarantee good system performance, unless we have a proper routing strategy in place that exploits the advantages of directional antenna. So, in this paper, an adaptive routing strategy is proposed that exploits the advantages of directional antenna in ad hoc networks through the selection of maximally zone-disjoint shortest routes. Zone-disjoint routes would minimize the effect of route coupling and improve the overall network performance. The proposed strategy ensures effective load balancing and is applied to design and implement both single path and multipath routing protocols in ad hoc networks with directional antennas. Simulation results obtained on QualNet network simulator shows the effectiveness of the proposed routing protocols.

Keywords: Ad hoc networks, Route Coupling, Directional antenna, MAC protocol, Routing protocol, Adaptive Routing, Multipath Routing, Maximally Zone-disjoint Routes.

1. INTRODUCTION

It has been shown earlier that the use of directional antenna in the context of ad hoc wireless networks can largely reduce the radio interference, thereby improving the utilization of wireless medium and consequently the network performance [1]. Recently, several MAC protocols with directional antennas have been proposed in the context of ad hoc networks in order to improve the medium utilization by allowing more number of simultaneous communications in the medium [3, 4]. However, an efficient directional MAC protocol alone would not be able to guarantee good system performance, unless we have a proper routing strategy in place that exploits the advantages of directional antenna. In this paper, an adaptive routing strategy is proposed that exploits the advantages of directional antenna in ad hoc networks through the selection of *maximally zone disjoint routes*. Two routes are said to be *zone-disjoint* if data communication over one route minimally interferes with data communication along the other. The proposed routing strategy ensures effective load balancing in the wireless medium and is applied to design and implement both single path and multipath routing protocols on ad hoc networks with directional antennas.

Let us consider the scenario in Figure 1 where S_1 is communicating with D_1 through N_1 and N_2. Now, if another source S_2 also wants to communicate with D_2 then, there are three possible paths: S_2-N_1-N_2-D_2, S_2-N_3-N_4-D_2 and S_2-N_5-N_6-D_2. If S_2 uses the first path, it overlaps with the path used by S_1, so simultaneous communications by S_1 and S_2 are not possible. If S_2 uses the second path, then directional transmission-beam formed by S_2 towards N_3 will create interference in N_1's reception from S_1. So, the route coupling occurs between S_1-N_1-N_2-D_1 and S_2-N_3-N_4-D_2 as two routes are located physically close enough to interfere with each other during data communication. This, in turn, will prevent these two communications to happen simultaneously even if directional antenna is used at each node.

*Corresponding Author

Although S_1-N_1-N_2-D1, S_2-N_3-N_4-D_2 are apparently independent node-disjoint routes, but routing performance will deteriorate in this context due to the presence of *route coupling* even if we use directional antenna. The impact of directional antenna on routing would be visible, if S_2 selects the third path i.e. S_2-N_5-N_6-D_2. These two routes S_1-N_1-N_2-D1and S_2-N_5-N_6-D_2 are coupled with each other, if nodes use omni-directional antenna (as shown with dotted line in Figure 1). But they are *completely decoupled*, if each node uses *directional antenna*, as shown in Figure 1. These two routes are said to be *zone-disjoint* with respect to each other.

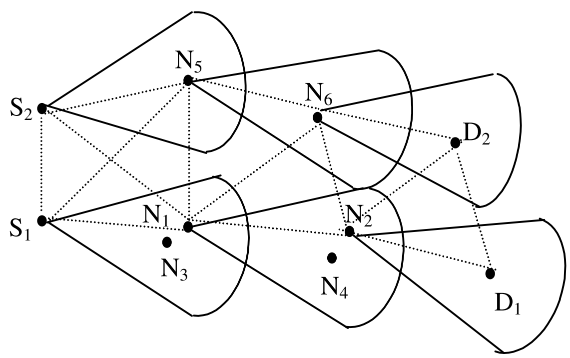

Figure 1. Zone Disjoint Communications between S_1 - D_1 and S_2 -D_2 with Directional Antenna

It is evident from the above discussion that zone-disjoint routes also ensure effective load balancing in the network by distributing traffic load among several nodes and this in turn offers two major advantages. First, it prevents loads concentrating on a set of nodes and spreads it among other nodes in a uniform manner, thereby reduces the possibility of power depletion of a set of heavily-used nodes; and, secondly, it distributes the traffic all over, thus reducing congestion and improving network performance. As illustrated in Figure 1, S_1-N_1-N_2-D1, S_2-N_3-N_4-D_2 are node-disjoint and consequently satisfies the criteria for load balancing. But, since they are coupled with each other, end-to-end delay will increase. This is because two paths have more chances to interfere with each other's transmission due to the broadcast feature of radio propagation. So, it is important to discover *zone disjoint routes* for *effective load balancing*. But getting zone-disjoint or even partially zone disjoint paths using omni directional antenna is difficult since transmission zone is larger. It has been shown that it is much easier to get zone-disjoint routes using directional antenna [2].

However, zone-disjointness alone is also not sufficient for performance improvement. Path length is also an important factor. A longer path with more number of hops (H) will increase the end-to-end delay and waste network bandwidth, even in the context of zone-disjointness. So, it is imperative to select *maximally zone-disjoint shortest paths*.

The advantages of using multipath routing scheme over traditional single path routing have been studied by several researchers [5-9] because this would eventually reduce congestion and end-to-end delay [2] in wireless medium. Apart from that it also diminishes the effect of unreliable wireless links in the constantly changing topology of ad hoc networks. M. R. Perlman et al. [7] demonstrates that multipath routing can offer better load balancing but their work is based on multiple channel networks, which are contention free but may not be available in most cases. In the Split Multipath Routing (SMR), proposed in [8], the notion of maximally disjoint multiple paths is explored. It has been pointed out in [7] that use of multiple paths does not necessarily result in a lower end-to-end delay. The network topology and channel characteristics (e.g., *route coupling*) severely limit the gain offered by Alternate Path Routing strategies. In this paper, we have used the same notion of zone-disjoint shortest path routing scheme for multipath routing. It has been shown that multipath routing is the best choice when number of communications is low. However, with increasing number of communication, single path adaptive routing performs better than adaptive multipath routing.

In our proposal, each node is *topology-aware* and *aware of communications going on in the network*. However, since this awareness at each node is acquired through periodic propagation of control message, it is only a *perception* about network status rather than *actual* network status. So, each intermediate node adaptively corrects and modifies routing decision depending on the more accurate local information currently available in its ANL and GLST during routing. We have evaluated the effectiveness of both single path and multipath routing schemes on QualNet Network Simulator with AODV [10] (as in QualNet) as a benchmark.

The paper is organized as follows. Section 2 includes basic definition of terms, description of antenna model and the basic information percolation mechanism in the network. It also contains a brief discussion on a location tracking mechanism and a receiver-oriented, rotational sector based directional MAC protocol.

Section 3 illustrates both single-path and multipath routing protocols using the notion of maximally zone-disjoint shortest routes. Section 4 depicts the performance evaluation on QualNet followed by concluding remarks in section 5.

2. SYSTEM DESCRIPTION

2.1 Some Important Definitions

Definition 1. When a node n forms a directional transmission beam with a beam-angle α and a transmission range R_{dir} with respect to n, the coverage area of n at an angle α is defined as **transmission_zone$_n$ (α)**.

Definition 2. We define **neighbors of node n (G^n)** as a set of nodes within the omni-directional transmission range R_{omni} of n.

Definition 3. A subset of G^n, $G^n{}_\alpha \in G^n$, is defined as the **directional neighbors of n**, when the nodes in $G^n{}_\alpha$ lie within its transmission_zone$_n$ (α).

***Definition 4*. Communication-id c** is essentially a unique id that specifies a source-destination pair for which the communication is on. In case of multipath communication from a source to a destination, a sub-id of that communication-id represents each of the multipath flow.

***Definition 5*. Active Node List** [ANL(t)] is a set of nodes in the network actively participating in any communication process at an instant of time t. Each active node in the list is associated with a **set C of communication-ids** for which it is active.

Definition 6. **Active Directional Neighbors of node n at transmission_zone$_n$ (α)** [$ActG^n{}_\alpha$ (t)] is a set of nodes within the transmission_zone$_n$ (α) that are actively participating in any communication process at that instant of time (i.e. belongs to ANL (t)). So, $ActG^n{}_\alpha (t) = G^n{}_\alpha (t) \cap ANL(t)$.

Definition 7. **Correlation factor of node n_i in a path P for Communication-id c** [$\eta^{ni}{}_c$ (P)], where n_j is the next-hop from n_i in path P and $\alpha(n_i \rightarrow n_j)$ is the transmission zone formed by n_i towards n_j in order to communicate with n_j, is defined as the sum of the number of communication-ids handled by each active directional neighbor of node n_i at transmission zone$_{ni}$ ($\alpha(n_i \rightarrow n_j)$) excluding the communication-id c. So, $\eta^{ni}{}_c (P) = \sum_{\forall n \in ActG\text{-}ni\text{-}\alpha(ni \rightarrow nj)\ (t)} (| C - c |)$. For example, if n_i has 2 active directional neighbors one is handling 2 communications and the other is handling 4 communications and if one of them is handling communication-id c, then [$\eta^{ni}{}_c$ (P)] will be 2+4-1 = 5. So, it is important to note that, if an active directional neighbor of a node n_i is active for current communication-id c, then the activity-status of that node for that communication-id is ignored for calculating $\eta^{ni}{}_c$ (P).

Definition 8. **Correlation factor η of path P for Communication-id c** [η (P)] is defined as the sum of the correlation factors of all the nodes in path P. So, $\eta (P) = \sum_{\forall ni \in P} (\eta^{ni}{}_c (P))$. When η (P)=0, path P is said to be *zone-disjoint* with all other *active paths*, where active paths are those paths participating in communication process at that instant of time. Otherwise, the path P is η–related with other active paths. Correlation factor is used to measure the degree of route coupling. It has been shown that larger the correlation factor, the larger will be the average end-to-end delay for both paths [2].

2.2 Antenna Model

We are working towards implementing Wireless Ad Hoc Community Network testbed [1] where each user terminal uses a small, low-cost adaptive antenna, known as ESPAR (Electronically Steerable Passive Array Radiator) antenna [1, 4] that relies on RF beamforming, and drastically reduces the circuit complexity. The ESPAR antenna consists of one center element connected to the source (the main radiator) and several surrounded parasitic elements (typically four to six) in a circle, which are reactively terminated to ground. By adjusting the value of the reactance, the parasitic elements form the antenna array radiation pattern into different shapes. In this work, we have used ESPAR antenna as a quasi-switched beam antenna. We have used an ESPAR antenna with 60-degree beam width and 12 overlapping patterns at 30-degree intervals. We have also used an *ideal directional antenna* with 45-degree beam-width and insignificant side-lobes to compare the effectiveness of ESPAR antenna.

2.3 Network-Awareness

The purpose of an information percolation mechanism is to make each node aware of the *approximate topology* and the *communication events going on in the network*. The objective here is to get accurate local perception, but approximate global perception of the network information. This approximate network awareness can be realized by implementing both MAC and an adaptive single and multipath routing protocol, as will be discussed subsequently. In order to track the direction of its neighbor, each node n periodically *collects* its directional neighborhood information through periodic beacons from each neighbor so that it can determine the best possible direction to communicate with each of its neighbor.

Each node n in the network maintains the following network-status information [11]:

Active Node List (ANL_n): It contains the perception of node n about communication activities in the entire network. It is a list in node n containing all active nodes in the network and each of them is associated with a set of communication-ids for which it is active.

Global Link-State Table ($GLST_n$): It contains the global network topology information as perceived by n at that instant of time.

Each node *broadcasts its ANL at a periodic interval*, say T_A. Broadcast of ANL serves two purposes: when a node n receives ANL from all 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. Node n records the communication activity status of node i, and similarly for other neighbors, thus forming its own ANL, depending on the recency of the received information [11]. Each node *broadcasts its GLST at a periodic interval,* say, T_G. When a node n receives GLST from its neighbors, it updates its own GLST, depending on the recency of the received information [11].

ANL needs to be propagated faster than GLST because ANL serves as beacon. So, by the faster propagation of ANL, not only the critical information of active nodes can be percolated faster, but also accurate neighborhood information (direction, signal level) can be obtained. GLST reflects the change of topology with respect to physical mobility (which is much slower compared to signal propagation). So, it need not be propagated very fast. The overhead can be controlled by adjusting T_A and $T_{G.}$ Current values of T_A and T_G are 200 milliseconds and 5 seconds respectively.

2.4 Directional Location Tracking and Directional MAC

In order to fully exploit the capability of directional antenna, apart from a directional MAC protocol it is also necessary to have a proper mechanism at each node to track the direction of its neighbors. In this work, we have used a rotational sector-based receiver oriented MAC protocol as suggested in our earlier work [4], which also helps a node to track the direction of its neighbors.

3. ADAPTIVE COMMUNICATION-AWARE ROUTING PROTOCOLS USING MAXIMALLY ZON- DISJOINT SHORTEST PATH

3.1 Maximally Zone-disjoint Shortest Single-path Routing

Traditional routing schemes generally use shortest path routing protocol to improve the network performance in terms of throughput. But when several communications use some common nodes to route their traffic along shortest path, congestion may occur at those common nodes, which in turn decreases the network throughput. In the context of wireless environment, not only common nodes but also use of common zone during routing increases the end-to-end delay because of route coupling. So, instead of shortest path, if a diverse zone-disjoint path (which is zone disjoint with respect to other existing flows) could be selected for a new communication, then that would definitely improve the throughput by reducing the congestion as well as coupling.

At the same time, hop count of the selected diverse route is also another concern in this context. Otherwise, under some communication scenario, it may so happen that, for a particular destination, each intermediate node tries to select a route avoiding the active zones and ultimately ends up traversing the entire network in search of a zone-disjoint route. To alleviate this problem, we propose to use two metrics as route selection criteria: correlation factor (η) and propagated hop count (H). As explained earlier, correlation factor of a route is inversely related to zone disjointness of that route with respect to other active routes. So, by minimizing both correlation factor and propagated hop count, maximally zone disjoint shortest path can be obtained. Each node in the network uses its current network status information (approximate topology information and ongoing communication information) to calculate the *suitable next hop* for reaching a specified destination so that (i) the interference with the nodes that are already involved in some communication gets minimized and (ii) if a packet at an intermediate node has already traversed multiple hops, then shorter hop routes towards destination gets more preference.

Link-cost (n_i ,n_j) during the current communication having Communication-id c = $\alpha + \eta^{ni}_c + \gamma H$ where ,

α = Initial link-weight (0.01 in our case; $\alpha << \eta_c$ and $\alpha << H$, as will be explained in the following section).

η^{ni}_c = The sum of the total number of communications (excepting the current communication c) handled by each active directional neighbor in the directional zone (n_i->n_j) (As explained in section 2.1).

H = propagated hop-count of the current packet for which route is being calculated.

γ = Weight factor (0.5 in our case). γ is to be adjusted in such a way that initially low-coupled diverse paths will be selected but progressively shortest hop route will get preference over η-driven route to ensure convergence. When H and η is zero, α is used to find out the shortest path. Dijkstra's shortest path algorithm has been modified to select a shortest-cost path.

3.2 Finding Maximally zone-disjoint shortest path: An Analysis

Let us assume that a packet, after propagating through H hops from source node, has arrived at an intermediate node n_i and it has to go to destination D. Let us also assume that the packet from n_i has two choices to reach destination D: a longer path (P_L) with low η and a shorter path (P_S) with high η. Let us also assume that the packet needs to traverse through h hops along P_S and through (h+x) hops along P_L to reach destination. If our strategy were to find out maximally zone-disjoint path, then obviously the longer path with low η would have been the choice. However, as discussed earlier, that would not be the optimal solution for improved throughput, as packets may get diverted towards longer path unnecessarily, increasing the end-to-end delay. In the following analysis, we are trying to estimate a strategy for selecting maximally zone disjoint *shortest* path.

As mentioned before,

Link-cost (n_i ,n_j) for the current communication with Communication Id c = $\alpha + \eta^{ni}_c + \gamma H$

So, sum of all link-cost on path P_L = α* (h+x) + $\eta_c(P_L)$ + γ * H * (h+x), where $\eta_c(P_L)$= Correlation factor η of path P_L for Communication-id c (Definition 8)

Similarly, cost of P_S = α* h+ $\eta_c(P_S)$ + γ * H * h

The longer path P_L will be selected if cost of P_L < cost of P_S,

i.e, if (α * (h+x) + $\eta_c(P_L)$ + γ * H * (h+x)) < (α * h + $\eta_c(P_S)$ + γ * H * h)

Case I. If $\eta_c(P_L)$, $\eta_c(P_S)$ and H are zero (initial condition), then P_L will never get selected.

Case II. If $\eta_c(P_L) = \eta_c(P_S)$, then also P_L will never get selected. This implies that if correlation factors of two paths were same, shorter path would be selected.

Case III. If $\eta_c(P_L) <> \eta_c(P_S)$, then the **longer path would be selected if**

($\eta_c(P_L)$ + γ * H * (h+x)) < ($\eta_c(P_S)$ + γ * H * h) [ignoring α * x, since $\alpha << \eta_c$]

or, **($\eta_c(P_S) - \eta_c(P_L)$) > γ * H * x**

This implies that, if the correlation factor of shorter path is more such that the difference in the correlation factor of shorter path and that of longer path is greater than γ * H * x, then the longer path will be selected.

Termination Condition. If H > 10, then shortest path is selected irrespective of the value of η.
If h=1 (i.e., next-hop is the destination), then the destination is selected.

Example1. Let us assume that the longer path is two hop longer than shorter path (x=2) and $\eta_c(P_S)$ = 9 and $\eta_c(P_L)$ =0. So, the longer path is totally zone-disjoint from all other active paths whereas the shorter path is having high correlation factor $\eta_c(P_S)$ = 9. The **longer path will be selected if 9 > 2*γ*H**

Case 1.1 H=8, $\gamma < 0.5625$ ⎝ Selects longer path
Case 1.2 H=8, $\gamma >= 0.5625$ ⎝ Selects shorter path

So, by adjusting the value of γ, we can adjust the preference between zone-disjointness and shortness of path. If γ is low, packet would tend to take long, bypass low-η routes, whereas, if γ is high, a packet would tend to take shorter routes. So, γ is termed as **dispersion factor**. Through several experimentations under different conditions, we have seen that the optimal value of γ is 0.5.

3.3 Maximally Zone-disjoint Multi-path Routing

Two key issues to be considered in multi-path routing are: i) *how many multi-paths*? ii) *how to select them*? It has been shown in our earlier work [2] that *two non-interfering routes are sufficient to achieve maximum possible throughput in case of multi-path routing*. Coupling-free routes are always the best choice in case of both single and multi-path routing, as they are free from the delay caused by mutual interference among the routes. So, the proposed multi-path routing scheme follows the unified zone-disjoint path selection method described in the previous section and selects a pair of maximally zone-disjoint shortest paths for each communication. This way our multi-path routing scheme is capable of balancing the network load, which in turn reduces the possibility of power-depletion of some heavily used nodes in the network as well as the probability of congestion and coupling. So, in case of multi-path routing, the source will basically transmit data packets along two zone-disjoint paths alternately.

4. PERFORMANCE EVALUATION

4.1 Simulation Environment

We have implemented the MAC protocol as illustrated in [4] and the routing protocol as illustrated in section 3 on QualNet network simulator [12] with ESPAR antenna and ideal directional antenna, as described in our antenna model. The set of parameters used is listed in Table 1.

Table 1. Parameters used in Simulation

Parameters	Value
Area	1500 x 1500 sq. m
Number of nodes	100
Transmission Power	10 dBm
Receiving Threshold	-81.0 dBm
Packet Size	512 bytes
CBR Packet Arrival Interval	2 ms to 500 ms
ANL Periodicity (T_A)	500 msec.
GLST Periodicity (T_G)	10 seconds

4.2 Impact of Overhead

Since both GLST and ANL are periodic update packets and their propagations are limited to one-hop broadcast, network would never get flooded with ANL or GLST, as discussed in detail in our earlier paper [11]. There we have assumed a network with N number of nodes within A sq.mt area and the omni-directional transmission range of each node is R. Thus the number of zones in area A in which update packets could migrate between nodes simultaneously, without mutual interference, equals (A / (πR^2)). So, the number of update packets that has to migrate from one node to another sequentially (say P) is as follows,

$$P = \frac{N}{A/(\pi R^2)} = \frac{N(\pi R^2)}{A}$$

Let us assume each update packet migrates at a time gap of T milliseconds and takes t millisecond to do so, the medium will be occupied by update traffic [t.P*100 / T] % of the time.

In our case, the bounded region of operation is 1500 × 1500 sq. m. and R is 300 m, T_{GLST} is 10 seconds and T_{ANL} is 500 msec. If time to broadcast one packet of 1024 bytes is 9 msec, then one typical GLST update packet containing 6 smaller fragments of 1024 bytes would take 9*6 i.e. 54 msec to reach next node in a 100-

node network. For ANL, the packet size is less than 1024 bytes even for 100 nodes. So, ANL does not require fragmentation.

Table 2. Overhead Analysis (Theoretical Values)

Number of nodes	t_{ANL}	t_{GLST}	Total Overhead (%) [GLST+ANL] (Theoretical)
60	2msec	9msec	3.69264
80	3msec	18msec	7.83744
100	6msec	54msec	21.8544

The results of both theoretical overhead analysis (Table 2) and simulation study of overhead (in Figure 2) show that the impact of overhead due to update packets is not at all significant for number of nodes 60. However, with increasing number of nodes, increase in overhead is significant. However, in spite of this overhead, the performance improvement in our protocol compared to that of AODV is always significant. Figure 3 shows that the experimental overhead is consistent with the calculated overhead. But, with increasing number of nodes, the deviation of experimental results with calculated results increases due to more interference in the medium.

It is to be noted here that the generation of control packets in our scheme is fixed and does not depend on the mobility or number of simultaneous communications. So, to summarize, the control overhead in our scheme is acceptable and is comparable, if not better, with other conventional scheme.

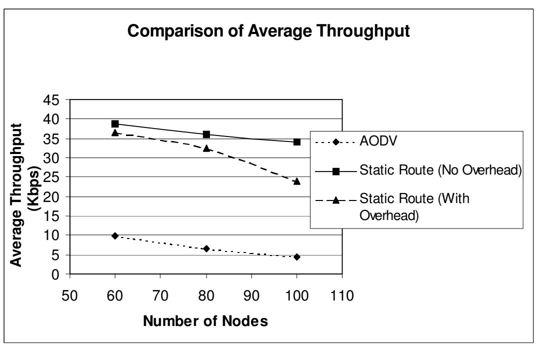

Figure 2: Impact of Overhead on Average Throughput

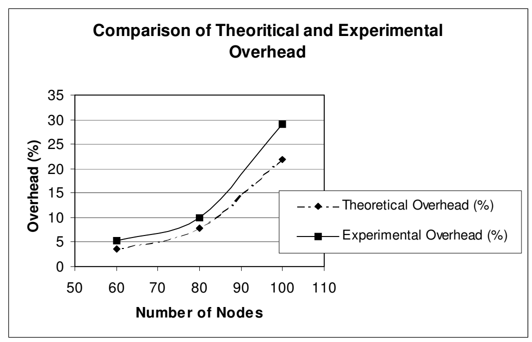

Figure 3: Comparison of Theoretical and Experimental Overhead

4.3 Evaluating ACR under Static Scenarios

We have used AODV with IEEE 802.11 as its MAC as a benchmark to compare and evaluate the

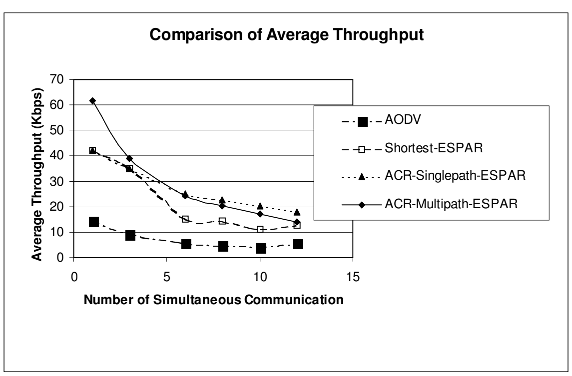

Figure 4: Comparison of Average Throughput with increasing number of simultaneous communication

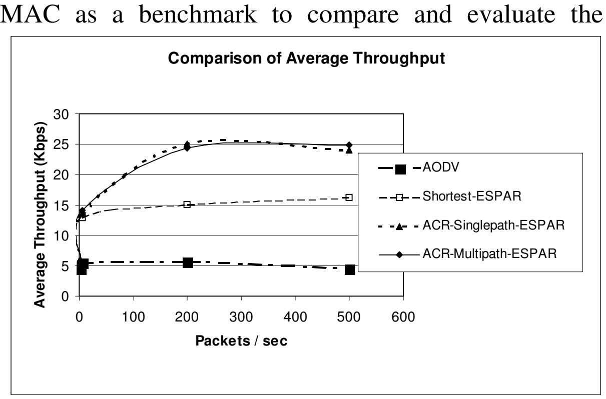

Figure 5: Comparison of Average Throughput with different packet arrival rate

performance of our proposal. We have evaluated ACR-Singlepath, ACR-Multipath and conventional shortest path routing: all with ESPAR antenna, and compared the throughput with AODV that uses omni-directional antenna. Initially, we have taken number of static snap-shots and observe the performance, as compared to AODV. The average of our observations are shown in Figure 4 and Figure 5 at (i) different number of simultaneous communication at a CBR packet arrival rate of 200 packets per second and at (ii) CBR packet arrival rate of 2 packets/second to 500 packets/second with packet size 512 bytes in a scenario of 6 communications.

In Figure 4, when the number of communications is low, route-coupling phenomenon is much less significant, so shortest path and ACR-Singlepath performance is the same. However, with increasing number of communication, the performance of shortest path routing degrades faster than that of ACR-Singlepath. When number of communication is 10, the ACR-Singlepath throughput is approximately double than that of shortest path. When the number of communications is low, multipath scheme easily finds a pair of zone-disjoint paths for each flow and ACR-Multipath outperforms other schemes. However, as the number of communication increases, say 4, then multipath scheme would generate eight flows, which in turn will create more contention and congestion. As a result, ACR-Multipath performance will degrade as compared to ACR-single-path. With increasing number of communication, AODV performance suffers because of (i) low SDMA efficiency due to the use of omni-directional antenna and (ii) route coupling. Therefore, the throughput of AODV is consistently low. ACR-Singlepath performance is 3 times (for low number of communication) to 5 times (for higher number of communication) more than that of AODV.

With multiple source destinations communicating at a time at high data rate, the utilization of the medium can be increased to a large extent using directional antenna. Along with this, if we select maximally zone-disjoint paths, this will further reduce the contention among nodes for getting access to the medium they share and can offer better load balancing. The combined effect of these two aspects will eventually improve the system performance drastically with improved throughput, as shown in Figure 5.

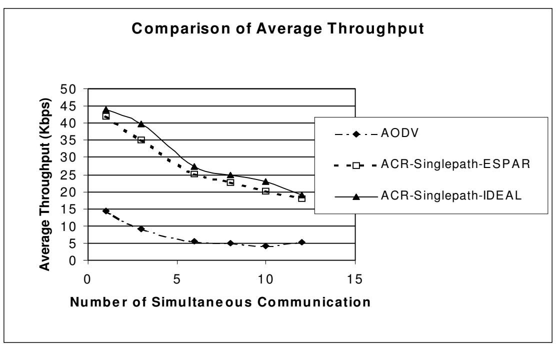

Figure 6: Performance of ESPAR antenna compared to IDEAL antenna with increasing number of simultaneous communication

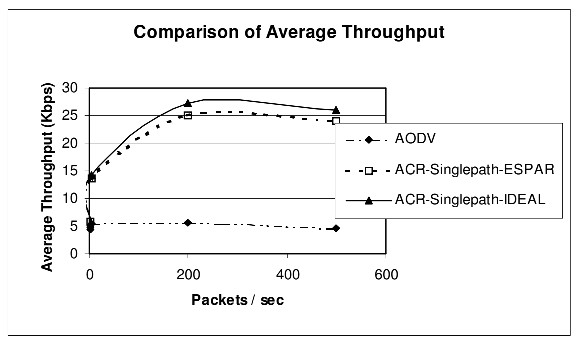

Figure 7: Performance of ESPAR antenna compared to IDEAL antenna with different packet arrival rate

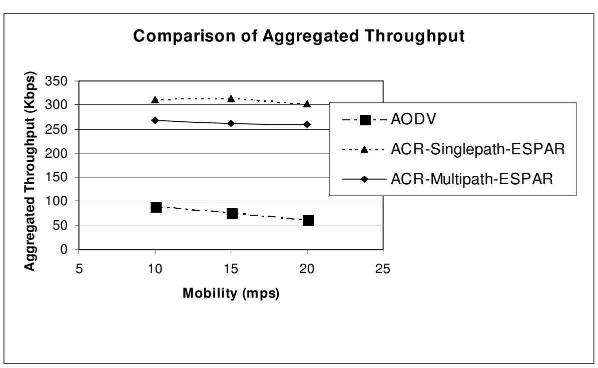

Figure 8: Comparison of Aggregated Throughput with increasing mobility

Figure 6 and Figure 7 shows that performance of ESPAR antenna is comparable to that of ideal directional antenna.

4.4 Evaluating ACR under Mobility

With mobility, the performance degradation of ACR scheme is much less significant as compared to that of AODV as shown in Figure 8. Since ACR scheme relies on table-driven, adaptive routing, intermediate nodes adaptively correct the initial routing decision to take care of route failures. On the other hand, as mobility increases, route errors due to route failures would increase, degrading the performance of AODV. The only impact of mobility on ACR is that, with increasing mobility, the network status information at any node tends to be less accurate and a packet may take longer route to reach destination because of adaptive route corrections at the intermediate nodes. Here, single-path routing performance is little better than multipath performance because the number of simultaneous communications is 6 in this scenario.

5. CONCLUSION

Use of directional antenna in ad hoc wireless network can drastically improve system performance, if we consider the issue of routing with load balancing along with suitable directional MAC protocol. Maximally zone disjoint shortest routes will be helpful in this context to reduce route coupling among selected paths and thereby improving throughput. In spite of the control overhead incurred due to periodic propagation of GLST and ANL in the network, the performance is far better than conventional reactive routing with omni-directional MAC protocol. Our table-driven adaptive routing with maximally zone-disjointness exploits the advantages of directional antenna and improves system performance. In any case, the performance of ACR scheme is always be better than conventional routing schemes with omni-directional antenna, especially when the system mobility is high and/or number of simultaneous communications is high.

It has been observed that performance of ACR-Multipath scheme may be worse than ACR-single-path performance if the number of communications is high. Based on this observation, we are currently investigating the feasibility of priority-based multipath routing where one or two high priority nodes will route data using ACR-Multipath, whereas other nodes will use ACR-single-path. This may improve the throughput of high priority flows. Another issue under investigation is scalability. We are also investigating the possibility of adjusting the periodicity of GLST propagation adaptively through the detection of node density and system mobility.

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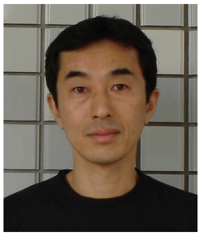
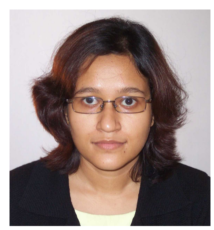


Tetsuro Ueda received his B.E.degree in electrical and communications engineering and M.E. degree from Tohoku Univeristy in 1986 and 1988. and joined NEC. He has researched channel allocation schemes and worked on the IMT-2000 standardization, He jointed KDDI in 1997, and moved to ATR Adaptive Communications Research Laboratories in 2001. His research interest is wireless ad hoc network.

Shinsuke Tanaka received his B.E. degree in material engineering and M.E. degree from Kyoto University in 1978 and 1980, and joined KDD. He has researched magneto-optical recording medium and semiconductor optical devices for optical fiber communications, and received his Ph.D degree in 1988. In 2002, he was appointed manager of the First Research Department, ATR Adaptive Communications Research Laboratories. His research interests are wireless ad hoc networks and communication quality.

Bokuji Komiyama received the B.S. and the M.S. degrees in electronics engineering in 1968 and 1970 respectively, and the Ph.D. degree in 1987, all from Tohoku University, Sendai, Japan. From 1970 to 1995, he was with the CRL (Communications Research Laboratories, currently reorganized to NICT), where he worked on low noise-frequency synthesis, superconducting cavity stabilized oscillators, and low loss material measurements at mm-wave region. He was with NBS Boulder, CO, from 1979 to 1980 as a Guest Worker where he studied low-temperature crystal oscillators. Since 1995, he has been with ATR, Kyoto, where he is presently the director of Wave Engineering Labs. His research interests include adaptive antennas, microwave photonics and wireless mobile communications. Dr.Komiyama is a member of the IEICE of Japan, the IEE of Japan, the Japan Society of Applied Physics and the IEEE.

Siuli Roy is a MCA (Master of Computer Applications) from Jadavpur University and currently working as Senior Research Engineer at Indian Institute of Management Calcutta in ADHOCNET Project. She is currently working towards her Ph.D. Degree on MAC and Routing Protocols for Ad Hoc Wireless Networks using Smart Antennas.



Dola Saha is a B. Tech in Information Technology from Netaji Subhas Engineering College and currently working as Research Engineer at Indian Institute of Management Calcutta in ADHOCNET Project. She is currently working towards her Ph.D. Degree on priority based service provisioning in Ad Hoc Wireless Networks using Smart Antennas.

Somprakash Bandyopadhyay is a Ph.D. in Computer Science from Jadavpur Universityand B.Tech in Electronics and Electrical Communication Engineering from Indian Institute of Technology, Kharagpur (1979). He is currently Professor of MIS and Computer Science Group of Indian Institute of Management, Calcutta. He is also acting as the Project Director of ADHOCNET Project at Indian Institute of Management Calcutta.