# A Priority-based QoS Routing Protocol with Zone Reservation and Adaptive Call Blocking for Mobile Ad Hoc Networks with Directional Antenna

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*Abstract*— **Existing priority-based QoS routing protocols in ad hoc wireless networks did not consider the effect of mutual interference between routes in wireless medium during routing. We have investigated the effect of mutual interference on the routing performance in wireless environment and explored the advantage of using zone-disjoint routes to avoid mutual interference and to improve the network performance. In this paper, a priority based QoS routing scheme is proposed that uses the notion of zone-disjoint routes. Our protocol avoids the contention between high and low priority routes by reserving high priority zone of communication. Low priority flows will try to avoid this zone by selecting routes that is maximally zone-disjoint with respect to the high priority reserved zone and will consequently allow a contention-free transmission of high priority traffic in that reserved zone. If, under some unavoidable situations, a low priority flow has to go through high priority reserved zone causing interference then it will block itself temporarily to allow contention-free transmission of high priority flows and later may resume the blocked communication if possible. We have evaluated the effectiveness of our proposed protocol on QualNet network simulator.**

***Keywords-Ad hoc networks; Directionl Antenna; Priority-based QoS;Zone-disjoint routes; Zone-reservation; Call-blocking;***

## I. INTRODUCTION

Numerous solutions to the QoS problems have been proposed so far in the context of ad hoc networks [1-5]. However, these protocols did not consider a major aspect of wireless environment, i.e., mutual interference. Interference between nodes on the routes within the proximity of each other causes *Route Coupling* [6]. The nodes on those coupled routes will constantly contend to access the wireless medium they share, and, as a result, QoS suffers. Even if node-disjoint routes (routes sharing no common nodes) are used for communication, the inherent route coupling among those node-disjoint routes may not allow them to communicate simultaneously and the routing performance in wireless environment degrades substantially. This can be avoided by using *zone-disjoint routes* [6]: two routes are said to be *zone disjoint* if data communication over one path does not interfere with data communication along other path.

In this paper, our primary objective is to devise a priority based routing scheme, which will protect the high priority flows from the contention caused by the low priority flows. Our protocol avoids the coupling between routes used by high and low priority traffic by *reserving high priority zone of communication.* The part of the network, used for high priority data communication, will be temporarily reserved as h*igh priority zone*. Low priority flows will try to avoid this zone by selecting routes that is *maximally zone-disjoint* [6] with respect to the high priority reserved zone and will consequently reduce the contention between high and low priority flows in that reserved zone. But, this does not ensure that the low priority flows will be able to avoid the high priority zone completely. As the number of high priority flows increases in the network, it becomes difficult for the low priority flows to find routes avoiding high-priority zones. Some topological situation may also occur where some low priority flows may not get a path through any unreserved part of the network. As a result, low priority flows will be forced to take routes through high priority zone, causing interference. This may be controlled by temporarily blocking such low priority flows in the system. Low priority flows will constantly monitor the reservation status of the network in order to find a path through unreserved zone. As soon as a low priority flow gets such a path, either due to mobility of nodes or end of high priority session, it immediately resumes the blocked communication. In this paper, we have discussed the effectiveness of low priority call blocking to improve the throughput of high priority flows in a network consisting of several coupled high and low priority flows.

QoS support in the context of ad hoc networks includes QoS models, QoS Resource Reservation Signaling, QoS Routing and Medium Access Control [1-5]. However, Xavier Pallot et. al. have proposed in [5] that limited bandwidth of the mobile radio channel prevents giving every class of traffic the same QoS except when the network is very lightly loaded. So, some means for providing each class a different QoS must be implemented by assigning priority to one class over another class in terms of allocating resources. Thus, linkage between *QoS* and *Priority* is a common one in the literature, and the two terms are almost synonym [5]. So, QoS provisioning through priority-based service is an interesting idea that is worth exploring.

Several efforts have also been made to support QoS in ad hoc networks by changing the size of contention window (CW) according to the priority of traffic in MAC layer and modifying *backoff algorithm* accordingly [7]. Since this approach is probabilistic, it does not guarantee that high priority packets will always get a contention-free access to the medium for data communication. Moreover, two high priority flows contending for the medium may not always get guaranteed fair access of the medium in these schemes.

Let us consider Fig.1, where $S_1$-$N_1$-$N_2$-$D_1$ and $S_2$-$N_3$-$N_4$-$D_2$ are two node-disjoint paths used by $S_1$ and $S_2$ to communicate with $D_1$ and $D_2$ respectively. Here $(S_1, S_2)$, $(N_1, N_3)$, $(N_2, N_4)$ and $(D_1, D_2)$ are within the omni-directional transmission range of each other (as shown in dotted line), as a result they cannot communicate simultaneously. So, even if node-disjoint routes are used for communication between $S_1$-$D_1$ and $S_2$-$D_2$, the inherent route coupling among these node-disjoint routes will not allow them to communicate simultaneously and the routing performance in this environment degrades substantially. So, it is evident that, in order to provide priority-based QoS, effect of route coupling should be minimized in case of high priority traffic so that they can get contention-free access to the medium to achieve better throughput.

Our objective is to exploit the advantage of zone-disjointness and use it to calculate diverse routes for low priority flows, which will minimally interfere with zone containing high priority traffic. But, getting zone-disjoint or even partially zone disjoint paths using omni-directional antenna is difficult since transmission zone of omni-directional antenna covers all directions. Directional antenna has a narrower transmission beam-width compared to omni-directional antenna. So, two interfering routes can be easily decoupled using directional antenna [6]. It has been shown earlier that the use of directional antenna would largely reduce radio interference, thereby improving the utilization of wireless medium and consequently the network throughput [6,8,9]. Fig. 1 illustrates that it is possible to decouple two node-disjoint routes $S_1$-$N_1$-$N_2$-$D_1$ and $S_2$-$N_3$-$N_4$-$D_2$ with directional antenna, which would not be possible if omni-directional antenna were used in this case.

The rest of the paper is organized as follows. Section II describes the concept and mechanism of selection of maximally zone disjoint routes in general. Using this notion, a priority-based scheme for providing QoS in ad hoc networks through adaptive zone reservation for high priority traffic and maximally zone-disjoint route selection for low priority flows is presented in section III. An adaptive call blocking mechanism is also suggested during low priority route calculation in this section to achieve further improvement in the performance of high priority flows. Effectiveness of our proposal is evaluated on QualNet Network Simulator and the experimental results are discussed in Section IV. Section V concludes the paper.

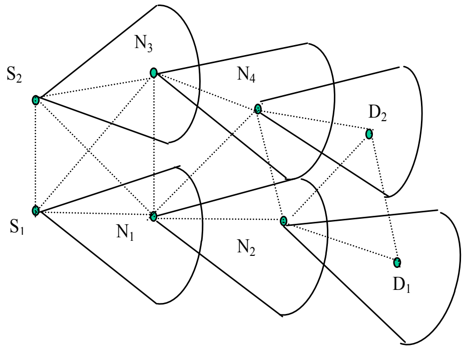

Figure 1. Zone Disjoint Communication between $S_1$ -$D_1$ and $S_2$ -$D_2$ with Directional Antenna

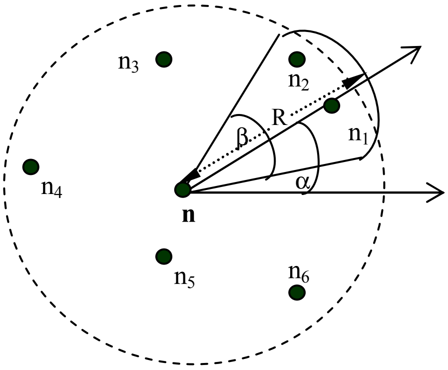

Figure 2. Transmission $\text{Zone}_n(\alpha,\beta,R)$ and omni-directional transmission range [*in dotted lines*] showing directional and omni-directional neighbors

## II. ZONE-DISJOINT ROUTE SELECTION FOR QOS ROUTING

In this section, we will discuss the key terms related to our proposal and will subsequently illustrate the basic mechanism to find zone-disjoint routes to avoid route coupling in wireless medium.

### A. Zone

When a node n forms a transmission beam at an angle $\alpha$ and a beam-width $\beta$ with a transmission range R, the coverage area of n at an angle $\alpha$ is defined as $\textit{transmission\_zone}_n(\alpha,\beta,R)$ (Fig. 2) of node n. Since transmission beam-width $\beta$ and transmission range R are fixed in our study, we will refer $\text{transmission\_zone}_n(\alpha,\beta,R)$ *as* $\textit{transmission\_zone}_n(\alpha)$ or, *Zone of* $\textit{commuication}_n(\alpha)$or, simply $\textit{Zone}_n(\alpha)$, in subsequent discussions. The nodes lying within the $\text{transmission\_zone}_n(\alpha)$ are known as the *directional neighbors of n* at an angle $\alpha$. Hence, only n1 and n2 are directional neighbors of n at an angle $\alpha$ in Fig. 2.

### B. High priority zone

It is the $\text{transmission\_zone}_n(\alpha)$ formed by any node n that is involved in high priority communication. If $n \rightarrow n_1$ is an *ongoing high priority communication* (Fig. 2), then $\text{transmission\_zone}_n(\alpha)$, shown in Fig. 2, is the *high priority zone*. The directional neighbors of n at an angle $\alpha$, i.e, $n_1$ and $n_2$, are then known as **reserved directional neighbors** as they are reserved for high priority communication, $n \rightarrow n_1$.

### C. Route Coupling

It is a phenomenon of wireless medium that occurs when two routes are located physically close enough to interfere with each other during data communication [6]. In Fig. 3, let, $n_1$- $n_7$ and $n_2$-$n_6$ be the two communications (represented by communication ids $c_1$ and $c_2$ respectively) present in a network at any instant of time. It is evident from the figure that the **zone of commuication$_{n1}$ ($\alpha_1$)** used by $c_1$ is interfering with **zone of commuication$_{n2}$ ($\alpha_2$)** used by $c_2$, which restricts the possibility of simultaneous communications $n_1 \rightarrow n_3$ and $n_2 \rightarrow n_4$. Correlation factor $\eta$ is used to measure route coupling [6]. *Correlation factor* $\eta$ of a node ni in a path P for communication $n_i \rightarrow n_j$ at an angle $\alpha$ with communication-id c [$\eta^{ni}c$ (P)], is defined as the sum of the number of communication-ids (C) handled by each reserved directional-neighbor of node ni within zone of commuication$_{ni}$ ($\alpha$) excluding the current communication-id c. In Fig. 3, if $n_1$-$n_7$ be a high priority on-going communication with communication id c1 which reserves two nodes ($n_3$ and $n_4$) and $n_2$-$n_6$ starts later with communication id c2, then correlation factor of node $n_2$, for communication id c2, will be calculated as follows. Here, $n_2$ has two directional neighbors, $n_3$ and $n_4$, which are already reserved by communication id c1. So, other than current communication c2, $n_3$ is handling one communication and $n_4$ is also handling one communication. So, correlation factor of $n_2$ for communication id c2 is 1+1=2. Correlation factor $\eta$ of path P for Communication-id c [$\eta$ (P)] is defined as the sum of the correlation factors of all the nodes in path P. It has been shown in [6] that m*inimization of both correlation factor and propagated hop count will give rise to maximally zone disjoint shortest path*.

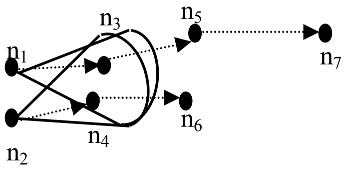

Figure 3. Route Coupling causes contention in wireless medium

### D. Zone reservation

To reserve the zone at a node n at an angle $\alpha$ for a communication $n \rightarrow n_1$ in Fig. 2, the status of node n and the status of each directional neighbor of n at an angle $\alpha$ are set as *reserved*. Thus, zone reservation essentially sets the status of all directional neighbors of a node at a particular beam pattern including that node as reserved so that other communications may avoid those reserved nodes during their route calculation process. Avoiding reserved zone of a communication actually eliminates the possibility of interference caused by other communications to that on-going communication. In our proposed protocol, zones reserved by high priority flows are avoided by low priority flows during their route selection process.

### E. Reserved Node List (RNLn)

It contains the perception of node n about high-priority communication activities in the entire network. As mentioned earlier, it is a set of nodes at an instant of time t where each node is either a sender or a receiver in any high priority communication process or a directional neighbor of this sender node. Each node in the list is associated with a **set of communication-ids** for which it is reserved. Thus, it seems that all the nodes in the RNL have reserved a part of the network, which is referred as *high priority zone*. Other low priority flows are not allowed to use that zone.

### F. Global Link-State Table (GLSTn)

It contains approximate network topology information as perceived by n at that instant of time [6]. Using this RNL and GLST, a node calculates route avoiding the zones containing reserved nodes as far as possible.

## III. PRIORITY-BASED QOS ROUTING

Our protocol assigns a path to a high priority flow that is shortest as well as maximally zone-disjoint with respect to other high-priority communications. Each low priority flow will try to take an adaptive zone-disjoint path avoiding all high priority zones. If such a path is not available, it will block the flow adaptively to protect high priority flows. Thus, for low priority flows, a shortest path criterion is not a predominant metric. However, unless we consider the hop-count or path-length of low priority flows, packets belonging to low priority flows may get diverted towards longer path unnecessarily, increasing the end-to-end delay. Moreover, there is no assurance of convergence i.e. the packets may move around the network in search of zone-disjoint paths but may not reach the destination at all.

### A. Zone Reservation and Route Computation by High Priority Flows

Each node in the network uses its current network status information (approximate topology information and ongoing high priority communication information) to calculate the *suitable next hop* for reaching a specified destination such that the interference with *reserved nodes* gets minimized. Initially, when a packet is transmitted from a source, it gives preference to the zone-disjoint path selection criteria. But, if a packet reaches an intermediate node after traversing multiple hops, then *progressively shorter hop route* towards the destination will be selected. So this adaptive route calculation mechanism guarantees the convergence of the proposed routing algorithm. We have used the following function to calculate the link-weights that will ensure the selection of lower $\eta$ path for low propagated hop count and selection of lower hop path for higher propagated hop count. Dijkstra's shortest path algorithm has been modified to select a path having smallest link-weight, i.e., total link-weight of all the links on that selected path will be minimum.

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

$\alpha$ = Initial link-weight (.01 in our case; $\alpha \ll \eta_c$ and $\alpha \ll H$)

$\eta^{ni}_c$ = Correlation factor of ni for communication-id c

H = propagated hop-count of the current packet for which route is being calculated. Propagated hop count indicates the number of hops already traversed by a packet at any point of time.

$\gamma$ = dispersion factor.

By adjusting the value of $\gamma$, we can adjust the preference between zone-disjointness and shortness of path. If $\gamma$ is low, a packet would tend to take long, bypass low-$\eta$ routes, whereas if $\gamma$ is high, a packet would tend to take shorter routes. So, $\gamma$ is termed as ***dispersion factor***. Through several experiments under different conditions, we have seen that the optimal value of $\gamma$ is 0.5 for high priority flows.

In our implementation, each flow in the network is identified with a unique id and belongs to either high or low priority category. Whenever a packet sent by high priority flow comes to a node for a particular destination, the node simply selects the *lowest-cost path* towards that destination and transmits the packet to the immediate next-hop on the selected path. The *lowest-cost path for high priority flow* is calculated as follows, according to the formula shown above.

Each link ($n_i$, $n_j$) in the network is initialized with a constant value i.e., $\alpha$. If any pair of nodes $n_i$ and $n_j$ are involved in some high priority communication, then all the nodes in the directional transmission zone of the sender $n_i$ towards receiver $n_j$ will set their activity status as HIGH to indicate that they should sit idle to support high priority transmission. They are treated as reserved nodes and are updated in their respective RNL. Link-weight of each link connected to a reserved node is assigned with additional link-weight depending on the calculated value of $\eta$ and $\gamma$ (=0.5) as per the formula described above. When a source of a high priority flow calculates its route, our path selection algorithm will automatically select maximally zone disjoint shortest path avoiding reserved nodes. If a reserved node does not receive high priority packet for a considerable period of time, then it will set itself as *unreserved* in its RNL so that other communications may select paths through it, if required.

### *B. Route Computation and Adaptive Call Blocking by Low Priority Flows*

#### *1) Route Computation without Call Blocking*

When call blocking is not used, the low priority flows try to select longer, diverse routes to avoid high priority zone as far as possible using the notion of *maximally zone-disjointness*. Whenever a packet sent by low priority source comes to a node for a particular destination, the node simply selects the *lowest-cost path* towards that destination and transmits the packet to the immediate next-hop on the selected path. The *lowest-cost path for low priority flow* is calculated using same formula with dispersion factor $\gamma$ =0.2. Low value of dispersion factor implies that the selected route will be longer than route selected with high value of dispersion factor. That means, low priority traffic will select a longer but diverse route to avoid high priority zone as far as possible whereas high priority traffic will select shorter diverse route with respect to other high priority flows to reduce interference among multiple high priority flows. This does not ensure that the low priority flows will always be able to avoid the high priority zone completely.

#### *2) Route Computation with Call Blocking*

Low priority source will consult its RNL and will try to select a zone disjoint route avoiding reserved nodes. At the same time, the total hop-count of such route should be less than a pre-defined maximum path length $LP_{maxhop}$ (18 hops in our case). If no such route is available, the low priority communication will be stopped temporarily. When the next low priority packet is to be transmitted, the node will try to find out a suitable route towards destination again as before. The absence of high priority flow in a high priority reserved zone for a long time automatically sets the status of a reserved node as unreserved which is updated accordingly in its reserved node list (RNL) and is periodically percolated throughout the network. So, it is possible that the low priority flow will be able to find a suitable route through unreserved part of the network now and will be able to resume the blocked communication. Thus, the low priority flows in our scheme are adaptively blocking and resuming the communication as per the demand of the situation to protect high priority flows.

## IV. PERFORMANCE EVALUATION

The proposed routing protocol is implemented on QualNet simulator using ESPAR antenna with 12 overlapping patterns at 30 degree intervals [6,10] as our directional antenna pattern to prove the effectiveness of our proposal. The simulation environment specifications and parameters used are described in Table I. Initially we have tried to establish that zone-reservation is an effective means to provide priority based QoS in ad hoc wireless network. For this, we have selected six random source-destination pairs (Flow1 to Flow6) as illustrated in Section A. But zone-reservation protocol alone does not work well in some scenarios where low priority flows do not get any suitable unreserved zone for routing and are forced to take route through the high priority reserved zone. This in turn affects the performance of high priority flows. In such situation adaptive call blocking of low priority flows is a necessity. To establish this fact, we have chosen random source-destination pairs in such a way that low priority flows do not get any suitable unreserved zone for routing. This is illustrated in Section B.

TABLE I. PARAMETERS USED IN SIMULATION

| Parameters | Value |
|---|---|
| Area | 1500 x 1500 m |
| Number of nodes | 100 |
| Transmission Power | 10 dBm |
| Receiving Threshold | -81.0 dBm |
| Sensing Threshold | -81.0 dBm |
| Data Rate | 2Mbps |
| Packet Size | 512 bytes |
| Simulation Time | 5 minutes |
| Mobility Model | Random Way-point |
| Packet Injection Rate | 15 ms |
| Topology | Random |

### *A. Effectiveness of Zone Reservation Protocol*

We have considered the following scenarios and initially observed the throughput of Flow1 (Fig. 4) when: i)Only Flow 1 is present in the network (shown in the Fig. 4 as “Flow1 As Single Flow”); ii) Flow1 is communicating in presence of 5 other Flows (Flow2 – Flow6) in the network and no priority scheme is used. (shown in Fig. 4 as “Flow1 With No Priority”); iii) A priority-based service differentiation scheme is employed. Flow1 is assigned *high priority*, thus takes the shortest path (shown in Fig. 4 as “Flow1With High Priority”). Moreover, Flow1 reserves a directional *zone* around each node on its route so that 5 other low priority flows will eventually select adaptive paths avoiding the zone reserved by Flow1.

In Fig. 4, it is observed that, in the first case, throughput of Flow1 is maximum, which is an obvious outcome of the fact that no other flow is causing any disturbance to it. In second case, as all the flows are using shortest path, existence of route coupling among those routes reduces the throughput of Flow1 drastically. But, in the third case, as soon as high priority is assigned to Flow1 and routes are selected according to our protocol, throughput of Flow1 shows a remarkable improvement, which is almost same as the throughput in the first case.

We have also observed (Fig. 5) the average throughput of the 5 low priority flows (i.e., Flow2 - Flow6) under the situation described above. Fig. 5 illustrates that if high priority is assigned to flow1 then average throughput of 5 low priority communications reduces a little bit in comparison to the corresponding average throughput when no priority is assigned to Flow1.

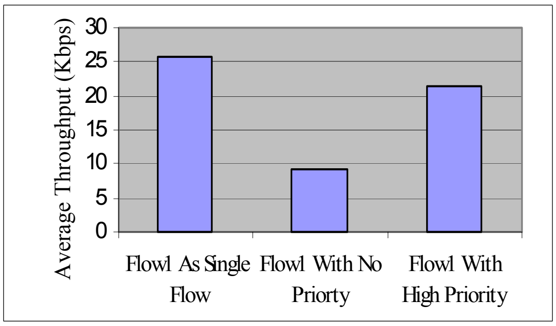

Figure 4. Behavior of a particular flow (Flow1) with Different Priority Assignments in a Scenario of 6 Communications

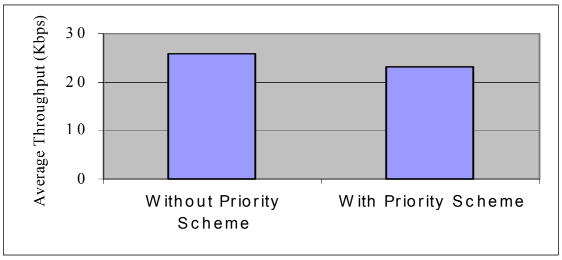

Figure 5. Behavior of 5 Low Priority flows with and without Assigning Priority to one Flow (Flow1) in a Scenario of 6 Communications

### B. Effectiveness of Call Blocking Scheme

Fig. 6 depicts a typical scenario where call blocking by low priority flow is the only way to protect high-priority flow from low priority interference.

In Fig. 7 the packet reception interval between two consecutive packets of each flow in a scenario of two coupled flows (one high and one low priority) throughout the simulation period is shown. In this scenario, the low priority flow starts at 90 Seconds and ends at 180 Seconds, whereas the high priority flow starts at 120 seconds and continues up to 150 seconds.

Here we are trying to show the effect of adaptive call blocking of low priority flow when low priority flow cannot find any unreserved zone from source to destination to route its packets. As the RNL is propagated to all the nodes in the network, the nodes become aware of the on going high priority flow in the vicinity and the low priority flow starts to block itself sensing the non-availability of suitable path avoiding reserved zone. When high priority source stops injecting packets after 150 seconds, then, low priority source again starts its communication. It is clear from this graph that only High priority flow operates during the period 120 to 150 seconds.

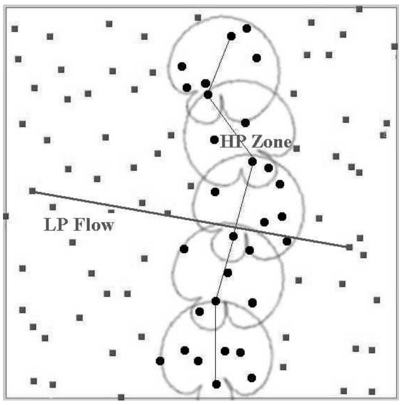

Figure 6. A typical scenario where call-blocking is necessary

#### 1) Single HP with Mutually Coupled Single LP Flow

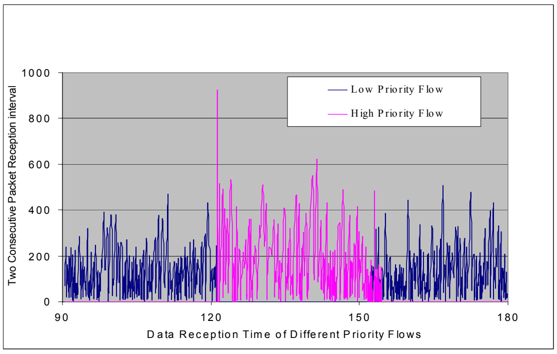

Figure 7. Adaptive Call Blocking of Low Priority Flow in presence of High Priority Flow

Initially we have chosen two coupled flows and assigned high priority to one of them. The routes are chosen in such a manner that low-priority flow has no other option but to go through some portion of the reserved zone of high-priority flow. The performances of high as well as low priority flow are compared before and after the implementation of call blocking mechanism. It is observed that high priority throughput is improving substantially by blocking the low priority flow which was creating contention to the high priority flow. The

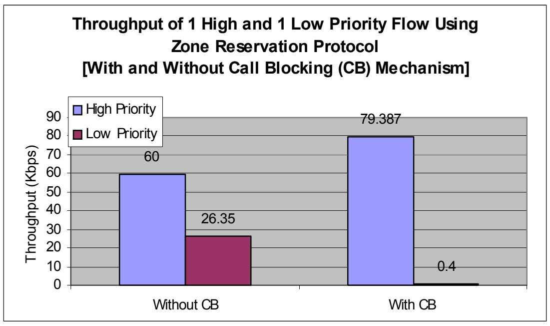

Figure 8. Effect of Call Blocking Mechanism on the Throughput of One High and One Low Priority Flow Coupled with Each Other

massive degradation of low priority throughput is due to call blocking. Since we have taken snapshots of static scenarios, where low priority flow is not getting any alternative path avoiding the high priority reserved zone, low priority flow has to block itself. Since it will take some time to take this blocking decision (depends on propagation time of RNL to source node), the throughput of low priority flow under call blocking is not zero, but close to zero.

### 2) *Multiple HP Flows with Multiple LP Flows*

#### a) *Static*

Fig. 9 illustrates the advantage of zone reservation protocol with call blocking as compared to simple zone-reservation protocol (without any call-blocking scheme). The scenario chosen is the average of a set of static setting with two high and three low-priority flows where all are coupled flows. As before, degradation of low priority throughput is due to call blocking and the delay in call-blocking decision allows the transmission of some low priority packets which is the cause of non-zero low-priority throughput.

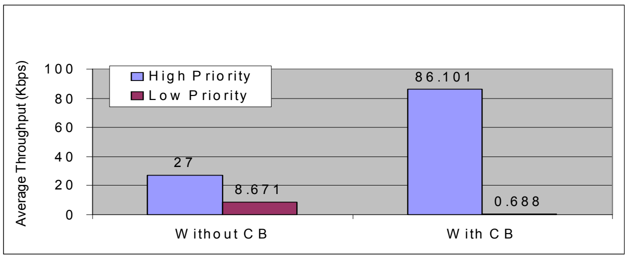

Figure 9. Effect of Call Blocking on the Average Throughput of Two High and Three Low Priority Flows Coupled with Each Other

#### b) *Mobility*

We have also evaluated the above scheme under moderate mobility (0- 10 mps) and the throughput performance of both high and low priority flows are shown in Fig. 10. Average throughput of high priroty flows is showing a phenomenal improvement using low priority call blocking technique compared to the corresponding throughput in simple zone-reservation-without call blocking technique. Moreover, as discussed earlier, degradation of low priority throughput in mobility scenario is much less compared to static scenario because, the low priority flows which block themselves without getting any path avoiding high priority resereved zone will be able to get alternate path under mobility, so it is possible to adaptively block and unblock the low priority flows according to the status of the network. Thus, low priority flows will perform better.

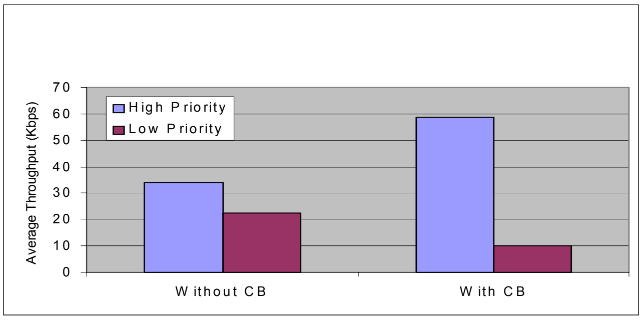

Figure 10. Effect of Call Blocking Mechanism on the Average Throughput of Two High and Three Low Priority Flows Coupled with Each Other Under Mobility (0-10 mps) Using Zone-Reservation Protocol

## V. CONCLUSION

In this paper, we have suggested a zone-reservation-based mechanism towards prioritized routing with the objective of providing an interference-free communication to high priority traffic. In order to improve the high priority throughput further, we have suggested adaptive call blocking of low priority flows. Here, unless narrow-beam directional antennas are used, it is not possible to accommodate multiple numbers of non-overlapping high priority zones. However, the paths would become less stable with narrow-beam directional antenna, when the nodes are mobile. Therefore, it is imperative to have adaptive call-blocking mechanism to ensure good performance of high priority flow under heavy traffic scenario. Currently, we are investigating on the impact of adaptive beam-width and transmission power control of directional antenna to improve the throughput of prioritized flow without degrading the low-priority flow to a large extent.

## ACKNOWLEDGMENT

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