Service Differentiation in Multi-hop Inter-Vehicular Communication using Directional Antenna

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Abstract— **Inter-vehicular communication (IVC) on highways is one of the major application areas of ad hoc networks that enable multi-hop data exchange and forwarding between cars and between car and stationary gateways. In an IVC scenario, some emergency situations on highways may require an immediate communication with police, hospitals, highway assistance booth or with other cars. These messages should be forwarded *on a top priority basis* to the destination for immediate attention. So it is evident that, in an IVC scenario, some message flows are to be treated as high priority messages in order to ensure a timely and reliable delivery. In this paper, we have proposed a priority-based communication scheme, which essentially selects shortest path for a high priority flow and reserves a zone known as *high priority zone*, along this path. Other low priority flows are forced to avoid this zone and take a longer diverse route to forward their messages to allow a contention-free communication to high priority flows. In this context, the use of directional antenna, having smaller transmission beam-width and larger transmission range compared to omni-directinal antenna, helps to easily decouple interfering routes, and improves the overall utilization of the wireless medium through Space Division Multiple Access (SDMA).**

Keywords- Inter-vehicular communication; Ad hoc Networks; Multihop communication; Priority based service-differentiation; Directional Antenna

I. INTRODUCTION

The emergence of mobile ad hoc networks has drawn the attention of the research community for their applicability in several real-time scenarios. Inter-vehicular communication (IVC) on highways is one of the major application areas in ad hoc networks that enable multi-hop data exchange and forwarding [1]. While driving, there is a constant need for local information regarding the roadblock, traffic condition, and any accident ahead. Also, in situations like medical emergency, information about some nearby hospitals or availability of doctors in nearby cars may be obtained through multi-hop data exchange and forwarding mechanism. However, these emergency applications may require some messages to be forwarded on a top priority basis to the intended destination that brings forward the issue of service differentiation among the data flows in the network. Service differentiation ensures that flows belonging to higher "service class" must receive better service [2]. Conventional approaches of changing the size of contention window (CW) according to the priority of traffic in MAC layer and modifying backoff algorithm accordingly does not ensure that high priority packet will always get a contention free access to the medium for data communication [3]. Service differentiation through end-to-end flow-rate control [2] is also difficult in such an unbounded, dynamic network.

In this paper, first, we have demonstrated the effectiveness of directional antenna in the context of IVC, which is depicted in Fig. 1(a) and 1(b). The communication zone formed by each transmitting node with omni-directional antenna covers all directions. But, directional antenna has a reduced transmission zone-width compared to omni-directional antenna. Use directional antenna would largely reduce radio interference, thereby improving the utilization of wireless medium and consequently the network throughput through improved space division multiple access (SDMA) [4,5]. Subsequently, we have proposed a priority-based communication scheme, where high-priority flow reserves a communication zone known as high priority zone. In our proposed scheme, a high priority zone is formed at each intermediate node on the path selected by a high priority flow. Low priority flows are forced to take longer and even congested route, if necessary, avoiding high priority zones. So, low priority flows should essentially choose a suitable next hop for forwarding its data, which is *zone disjoint* [4] with respect to high-priority traffic.

If a low priority flow cannot select paths avoiding high priority zones, that flow may be blocked temporarily to save high priority flows from low priority interference. This scheme uses some kind of "capture" of the network resources (which is wireless medium itself in this case) through reservation of zone adaptively by the high priority traffic. In Fig. 1(c), we have shown the initiation of a high priority flow in the middle lane, which will force the low-priority flow along the middle lane towards third lane, thus reducing the effect of interference between high and low priority flows. Fig. 1(d) demonstrates a situation where low-priority flow will be blocked to accommodate interference-free high priority flow. This scheme ensures a timely and reliable delivery of high priority data by minimizing the effect of interference caused by low priority flows in high priority communication zone.

II. ROUTING IN UNBOUNDED NETWORK

In this section, we will discuss the major issues related to routing in an application like inter-vehicular communications,

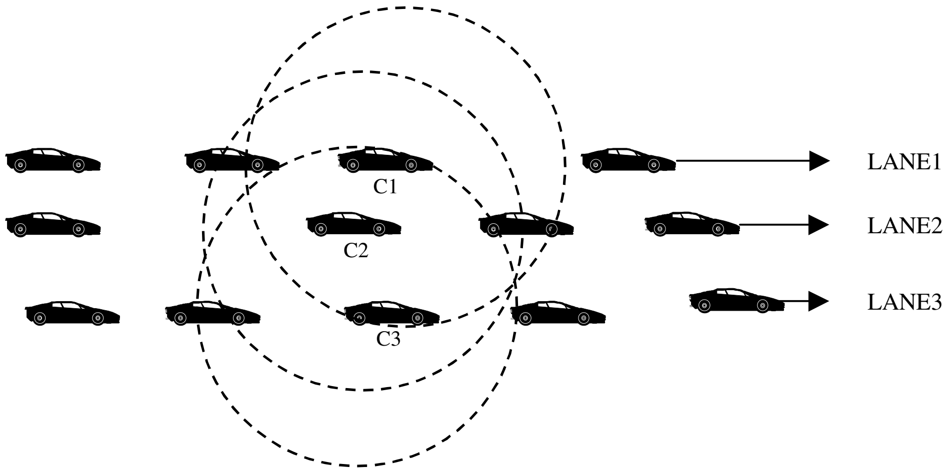

Figure 1(a). Overlapping transmission-zones of cars C1, C2 and C3 using omni-directional antenna inhibits the possibility of simultaneous communication among the vehicles along the lanes 1, 2 and 3

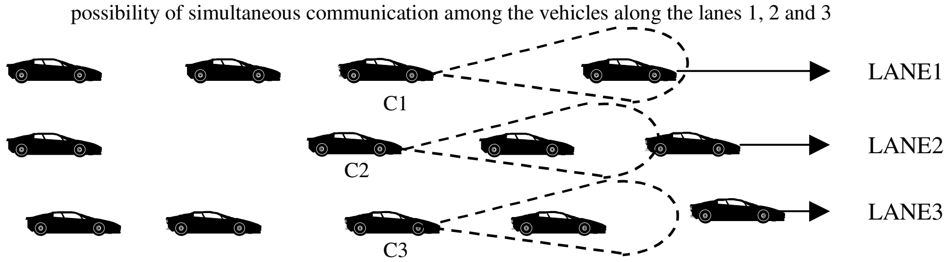

Figure 1(b). Non-overlapping transmission-zones of cars C1, C2 and C3 using directional antenna enhances the possibility of simultaneous communication among the vehicles along the lanes 1, 2 and 3

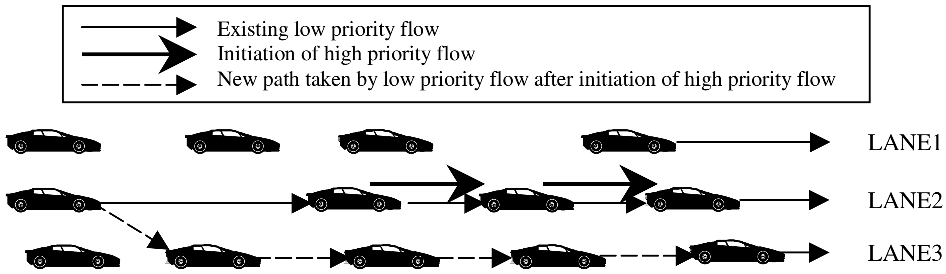

Figure 1(c). Initiation of a high priority flow from a car in LANE2 handling an existing low priority communication causes the low priority flow to take a diverse route along LANE3.

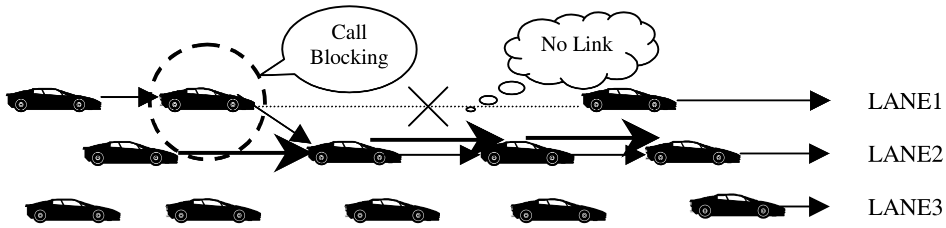

Figure 1(d). Initiation of a high priority flow from a car in LANE2 handling an existing low priority communication forces the low priority flow to block itself due to the absence of any other alternative path

which is essentially an unbounded network and will subsequently illustrate the key terms related to our proposal.

A. Bounded vs. Unbounded Networks

Immense research has been done and several schemes have been proposed in the context of routing in wireless environment. But those schemes generally assume that the networks under consideration are bounded wireless networks. So, a required destination can be found out either proactively or reactively from that bounded region. In a proactive scheme each node in the network maintains the approximate network topology information through periodic exchange of some kind of control packets. So, in order to route a packet to a specific destination each node just consults its topology information.

On the other hand, reactive routing schemes search for a destination on demand basis through propagation of Route Request/Route Reply packets.

In case of an inter-vehicular communication scenario, it is not always possible to identify a destination in advance. For example, if an immediate communication with some doctors is required on highways in case of any medical emergency then, passengers of each car have to be interrogated to find whether a doctor is available in that car or not. If a doctor were found in any car then that car would be the desired destination of the message. So, in IVC scenarios, content-based routing schemes [6] are generally employed, where a source node does not have any idea of the destination of the message beforehand. The nodes whose interests will be satisfied by the content of the message will be chosen as the destination. If the content satisfies the interests of more than one node then there may be more than one destination of such messages. So, in such cases, a source node will issue a route request to search for a suitable destination of a message to its neighbors and each neighbor in turn forwards the same to their neighbors and so on. This way the route request gets forwarded in search of a destination. Each node on receiving the message will check whether the content of message matches its interest. If that matches then that node will be the prospective destination. It is evident from the above discussions that proactive routing protocols are difficult to apply in IVC scenario because of lack of prior knowledge about destination and unbounded area of network. Only possibility that can be explored in such scenarios is to reactively find out suitable destination to route a packet.

In this paper, we have proposed a priority-based routing technique for achieving service-differentiation in multi-hop inter vehicular communication.

B. Application-dependent Route Discovery Process

In some applications like "looking for a doctor in near-by car for on the fly interactive consultancy" or, "exchange of emergency information between police patrol cars on highways", the route request for the message should be transmitted omni-directionally by the sender issuing the emergency message. The omni-directional transmission of route request in such cases will enable the source node to search for the required destination (doctor/police) across the highway in both forward and backward directions wherever the destination is available.

But, an information about a road-block or accident ahead is required to be passed in the backward direction only to inform other vehicles along that route so that they can take an alternate route accordingly using the prior knowledge of accidents/road block. Besides that, the near-by police station on the way back from the accident spot should be informed urgently for necessary assistance. These are the applications where backward transmission of route request is sufficient to find destinations.

On the contrary, if some information about a critical patient moving in a car is to be communicated with a near by hospital for emergency hospitalization of the patient then it is sufficient to transmit such route requests in the forward directions. In such cases, required destinations will be available in the forward directions.

So, the route-request forwarding techniques are entirely dependent on the nature of applications. The source node, requiring the communication, has to decide whether a particular application requires an omni-directional transmission of route requests or directional transmission in either forward or backward directions. If omni-directional transmission of route request is required for any application then the source node only will broadcast the route-request omni-directionally to all its neighbors. It is sufficient for other nodes, receiving the route-request, to forward it in the reverse direction with respect to the direction of arrival of the request packet in order to maintain loop-free and possibly minimal forwarding paths for messages. Since nodes are equipped with directional antennas, forward or backward propagation in a single direction is possible which minimizes contention in the medium.

In the proposed priority based routing scheme, the selection of propagation process (Forward/Backward/Omni) to be used for a route-request issued by any source is only dependent on the requirement of the specific application. So, both high and low priority sources may use any of the above-mentioned propagation process as per their necessity.

C. Zone

When a node n forms a transmission beam at an angle α and a beam-width β with a transmission range R, the coverage area of n at an angle α is defined as **transmission_zone$_n$(α,β,R)** (Fig. 2) of node n. Since transmission beam-width β and transmission range R are fixed in our study, we will refer **transmission_zone$_n$ (α,β,R)** as **transmission_zone$_n$ (α)** or, **Zone of commuication$_n$(α)**or, simply **Zone$_n$(α)**, in subsequent discussions. The nodes lying within the transmission_zone$_n$ (α) are known as the directional neighbors of n at an angle α. Hence, only n_1 and n_2 are directional neighbors of n at an angle α in Fig. 2.

D. High priority zone

It is the transmission_zone$_n$ (α) formed by any node n that is involved in high priority communication. If $n \rightarrow n_1$ is an

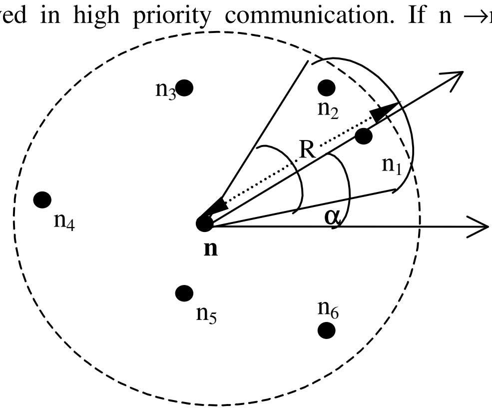

Figure 2. Transmission Zone$_n$(α,β,R) and omni-directional transmission range [*in dotted lines*] showing directional and omni-directional neighbors

ongoing high priority communication (Fig. 2), then transmission_zone$_n$ (α), shown in Figure 2, is the high priority zone. The directional neighbors of n at an angle α, i.e, n_1 and n_2, are then known as **reserved directional neighbors** as they are reserved for high priority communication, $n \rightarrow n_1$.

E. 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 [4]. 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$_{n1}$ (α_1)** used by c_1 is interfering with **zone of commuication$_{n2}$ (α_2)** used by c_2, which restricts the possibility of simultaneous communications $n_1 \rightarrow n_3$ and $n_2 \rightarrow n_4$. The contention between two communications for accessing the medium will result in high end-to-end delay and the performance of each interfering communication will suffer. So, it is evident that elimination of route coupling between two

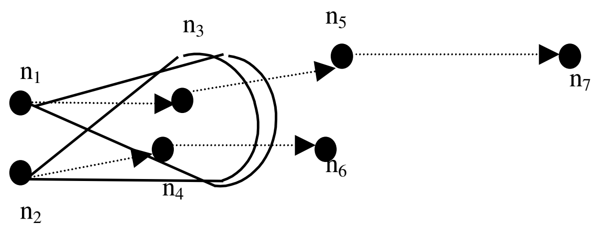

Figure 3. Route Coupling causes contention in wireless medium

interfering routes will definitely lead to improved network performance.

F. Zone reservation

To reserve the zone at a node n at an angle α 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 α are set as *reserved*. Thus, during zone reservation each directional neighbor of a node at a particular beam pattern including that node itself essentially sets their status 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.

III. Implementation of Prioritized Routing Scheme

To implement the proposed priority based routing scheme, each node periodically transmits omni-directional beacon containing its node-Id and activity status, which can be either *high* or *low*. The default activity status of each node is *low*, which indicates that it is not within any high priority zone. Each packet of a flow is tagged with the priority (high or low) of the corresponding flow. On receiving or overhearing high priority data packet, each node within the directional transmission-zone of the sender towards the receiver sets its activity status as *high*. This status is retained for a predefined time interval, after which the node resets its status back to *low* to indicate that the node is no longer within a high priority zone. Each node, on receiving a beacon from each of its neighbors, forms a table, known as Neighborhood Direction Status Table (NDST), which is derived from Angle-Signal Table (AST) that is required to implement directional MAC protocol [5] and essentially contains node-Id of the sender node, the direction of arrival of the beacon from the sender node and activity status of the sender.

According to our scheme, a source will initially send a route-request packet containing the subject of the message to search suitable destinations. Whenever route-reply packets are propagated back by prospective destinations to the source issuing the route request, the source will select a suitable route. A source generally selects a shortest-cost route towards the chosen destination from the list of routes that are piggybacked with route reply packets.

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

In case of high priority messages, route-request packets are transmitted omni-directionally or directionally either in forward or backward direction depending on content of the message. Other nodes, receiving the request, will forward it in the reverse direction with respect to the direction of arrival of the request packet thus minimizing the search space. If an intended destination is found on the way then the destination will inform the high priority source about the route to be taken to reach that destination. Among the several alternative routes available to the source to reach a destination, the shortest one will be selected.

As a high priority flow is initiated, the nodes in the high priority zone set their activity status as high. This information is eventually communicated to their neighbors through beacon, which in turn updates their NDSTs. Thus each neighboring node becomes aware of the high priority ongoing communication in the vicinity.

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

Any node handling low priority flow selects a node m as its next hop towards the intended destination, only if the directional transmission zone from that node to m does not contain any node with high activity status in its NDST. In order to select such a route avoiding high priority reserved zone, a low priority source will essentially transmit its route-request packet, using directional antenna, in all the sectors excluding the sectors containing active nodes. It is possible to form such multiple beams along different sectors using steerable-beam forming antennas. A node, on getting low priority route-request, will forward the request packet as before in all sectors excepting the sectors containing high priority nodes. Thus, each route-reply packet, sent by a destination to the low priority source, would contain a route that avoids high priority zone.

If no such route is available for routing low priority traffic, then the source node will temporarily block the low priority flow until the high priority zone is released by high priority flow. Low priority source will check the NDST continuously to resume its transmission. So, whenever a high priority communication within a high priority zone is absent for a considerable period of time, then the nodes belonging to that zone set their activity status as *low* and a blocked low priority source may re-initiate its route discovery process through that zone.

If an intermediate node on a low priority route, senses that a new high-priority communication has been initiated in its vicinity and the path to be taken by the node towards destination has to pass through the newly formed high priority zone, then the node will try to rediscover a route avoiding that zone. If it fails to find such route it will send an error signal to inform the source to discover a new route towards destination. The low priority source node tries to find new route avoiding high priority zone. If it is not found, source will temporarily block the flow.

PERFORMANCE EVALUATION

The results in Fig. 4, 5 and 6 are obtained using QualNet Simulator [7] with two parallel strings acting as two lanes of one-way highway. Fig. 4 shows the advantage of using Directional Antenna over Omni-directional Antenna with increasing number of hops. Fig. 5 shows the effectiveness of our priority-based scheme over non-prioritized scheme. The result shows that if high priority is assigned to a particular flow in a scenario of two flows and zone reservation protocol is employed with that flow then it will perform far better than the case where no priority assignment is made to that flow. Fig. 6 shows the behavior of a low priority flow with and without assigning priority to the other flow. Result indicates that if high priority is assigned to one flow then the other flow having no priority will suffer. But, that in turn helps the prioritized flow to continue its communication without any interruption caused by the other flow.

ACKNOWLEDGMENT

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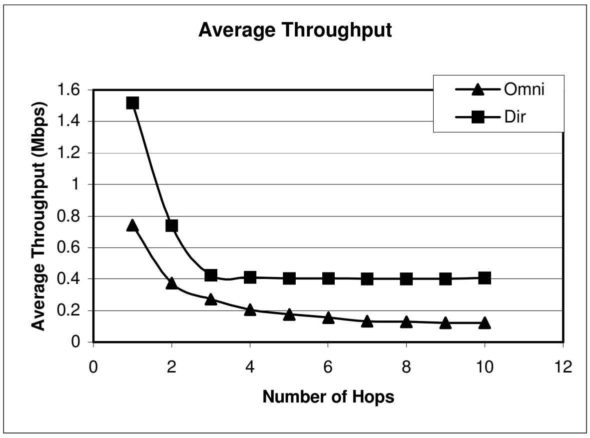

Figure 4. Comparison of AverageThroughput of two flows using Directional and Omni-directional Antenna with increasing number of hops

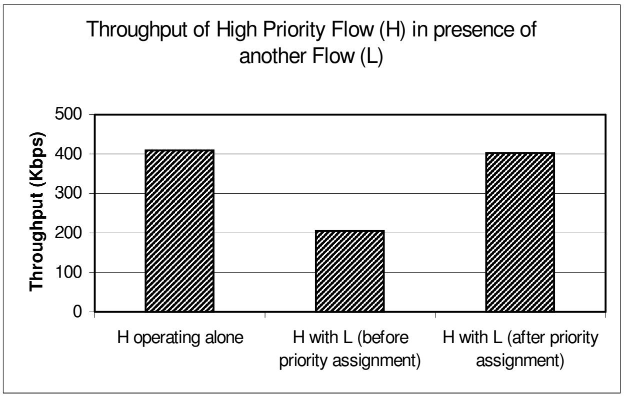

Figure 5. Throughput of a High Priority Flow (H) in presence of another Flow (L) with and without Priority Scheme

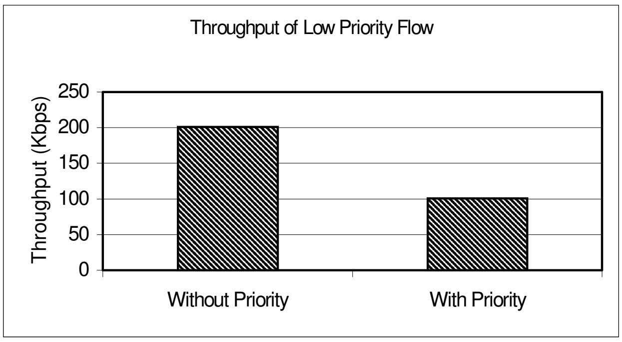

Figure 6. Throughput of a Low Priority Flow in presence of another Flow with and without Priority Scheme