A Scheduling Policy for Dense and Highly Mobile Ad Hoc Networks

Marceau Coupechoux*°, Christian Bonnet*, and Vinod Kumar°
*Mobile Communications Group, Institut Eurécom, Sophia Antipolis France, cbonnet@eurecom.fr
°Research and Innovation, Alcatel CIT, Marcoussis France,
{marceau.coupechoux,vinod.kumar}@ms.alcatel.fr

Abstract — Recent publications in information theory demonstrated that mobility can increase the capacity of wireless ad hoc networks. More precisely, the throughput per source-destination pair can be kept constant as the density of nodes increases. Indeed, such enhancements are achievable as the node mobility provides a sort of multi-user diversity. Considering an analytical study as a starting point, in this paper we propose and evaluate a distributed scheduling policy for dense and highly mobile ad hoc networks. Moreover, simulation results to show the benefit of mobility on the network capacity are provided.

Introduction

In recent years a lot of effort has been spent in the design of routing and medium access protocols for mobile ad hoc networks (MANETs). Such networks operates without any fixed infrastructure. Thus distributed processing is required for medium access as well as establishing a simple hop or a multi-hop route between a source and a destination. As a consequence, routing and medium access protocols have a lot of impact on the system performance and are very challenging issues.

Routing and MAC protocols have been mostly studied separately. From the literature related to routing schemes, classification can be as a function of system design choices:

1. Proactive versus reactive versus hybrid protocols,
2. Protocols for flat or hierarchical network architecture,
3. Global position versus global position-less based protocols.

Some of the main performance metrics are a minimum hop count and delay to destination, a fast adaptability to link changes, a stable route selection, the loop avoidance, and the power-awareness [1].

Studies related to MAC sub-layer focus on one or more of the following issues:

1. Family of problems related to multiple access such as the hidden and exposed terminal problem, spatial reuse of the radio resource and the spectral efficiency considering the collision avoidance,
2. The reliability,
3. The congestion control,
4. The fairness in the distribution of channel resources among the nodes,
5. The energy efficiency.

Numerous methods have been developed by researchers in order to deal with these issues. Floor acquisition protocols (the use of handshakes, carrier and packet sensing, tree-splitting, or busy-tone), techniques based on multiple channels (frequency hopping, packet scheduling or code assignment), spatial reuse (using directional antennas or power control), congestion window, and Back off algorithm are examples of tools proposed in the literature for the MAC sub-layer.

Related Work

In a recent paper [2], P. Gupta and P. R. Kumar have opened a new area of research related capacity of fixed ad hoc networks. Their main conclusion is that this capacity decreases approximately like $1/\sqrt{n}$, where n is the density of nodes, even with optimal scheduling and routing schemes. For a given node density, the system throughput is limited on the one hand by interference when the number of hops is small, and on the other hand by the amount of traffic if the number of hops is high.

However, M. Grossglauser and D. Tse proved in [3] that this limitation can be overcome through node mobility. In a cellular multi-user diversity scheme, the only user who is allowed to transmit to the base-station at any given time is the one with the best channel conditions [4]. By analogy, it is claimed that mobility brings a substantial increase in system capacity of ad hoc networks. In fact, radio link diversity provided indirectly by node mobility leads to a capacity enhancement, espacielly if no more than one relay node between each active source and destination pair is considered. As shown in Figure 1, in a dense network, the probability of finding adequatly matched source and destination nodes as well as the same for finding relay nodes as and when required, increases with node mobility. A centrally controlled scheduling policy described in [3] is based on a two phase transmission methode, i.e., from source to a waiting queue in the relay node and then from relay node to destination.

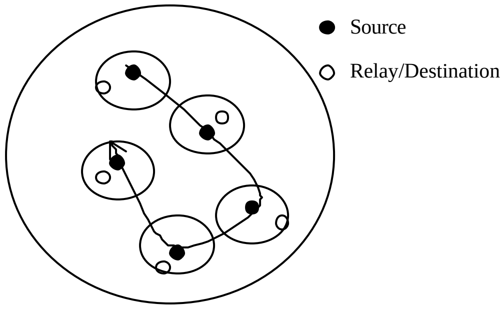

Figure 1 The source disseminates packets along its route (taken from [5])

However , it is well known that distributed scheduling policies are more suitable for implementation in ad hoc networking applications. In this paper, we describe the usefulness of such a scheme for capacity enhancement in mobile ad hoc networks.

Scheduling Policy and Modeling

In the proposed scheduling policy, the network is assumed to be perfectly synchronized. The number of nodes is N and they are mobile in a unit area disk. Each of them can be a source , a destination , or a relay, for a communication. The number of hops for a packet can be limited depending on the chosen strategy.

In the two-hop strategy, each node manages two packet queues between the MAC sub-layer and the packet generator. One of these, called the source queue, stores packets coming from its own packet generator. The other one, the relay queue, stores the incoming packets that have to be relayed. At each time-slot (ts) , θN nodes are designated as senders, the remaining nodes are receivers. This is done in a distributed way by generating a uniform random variable in each node and comparing the result with the predefined parameter θ, called the sender density. A source entering in the communication range of a receiver looks in its queues for any packets destined for this node. The source queue has priority over the relay queue. Any such existing packet is transmitted. Otherwise, a packet is chosen in the source queue to be transmitted to the receiver/relay. Packets have a fixed length, so that the transmission is possible within a time-slot. The basic idea is that a source dispatches packets to many intermediate nodes. Hence, at the stationary state each destination has a packet to receive from the relay that is in its communication range.

The performance of this baseline case is compared with the one-hop and the three-hop strategies. In the former, transmission occurs only when source and destination nodes are close together. In the latter, each node manages three queues where are stored packets from its own traffic generator, packets incoming from a source, and packets incoming from a relay. Thus, a maximum of three hops is allowed. Priority is given to the first queue and then to the second one.

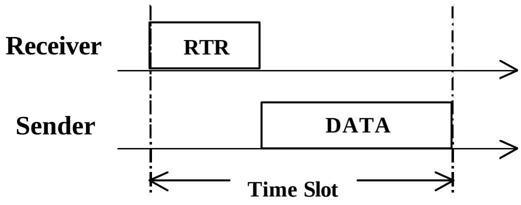

Figure 2 Two-way handshake within a time-slot

Two underlying MAC protocols are considered for communication between source and relay or destination.

The first one is similar to MACA-BI [6] and is a two-way handshake protocol. During a given time-slot, receivers send a RTR message (Ready To Receive). The receiver address is included in the message. A sender receiving an RTR looks in its queues for a packet for this destination receiver. Any such existing packet is transmitted. Otherwise, a packet is chosen in the source queue to be transmitted to the receiver/relay. Packets have a fixed length, so that the two-way handshake is possible within a time-slot (see Figure 2). There is no collision avoidance mechanism, thus some packets can be lost.

The second underlying MAC protocol is a four-way handshake with no loss of data in a perfectly slotted environment. The communication is initiated by the receiver. It sends a Ready To Receive packet (RTR) with its own address. Senders who have a packet to send to this receiver transmit a common pattern in order to acquire the floor. The pattern is made of several mini-slots. The number of mini-slots, called the priority number, is uniquely associated to the node address, so that at most one node is allowed to transmit at the end of the acquisition period. The receiver sends back a new RTR with the address of the unique sender, as shown on Figure 3. This sender is then allowed to transmit a data packet.

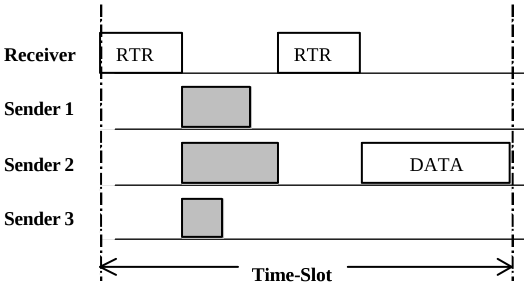

Figure 3 Four-way handshake within a time-slot

The receiver waits for the required number of mini-slots before sending the second RTR, so as to maintain constant duration time-slots. For the simulation, the initial priority number is set to the node identification number, between 0 and N-1, where N is the number of nodes. At each time-slot, the priority number is incremented by one modulo N, so that fairness in the channel access is aproximatly achieved among the nodes after a sufficient time of simulation. The second RTR is necessary because of the hidden terminal problem.

The traffic, mobility, and propagation models are described below.

The positions of the nodes are random variables uniformly distributed over an open disk of unit area. These random positions are drawn at each time-slot and nodes are assumed to be fixed during a single time-slot. Alternatively, another mobility model is considered that is called the random way-point model: For each node, a destination in the disk of unit area is chosen with an uniform random variable. A speed is chosen for this node and for this destination in the interval [0;vmax], where vmax is the maximum allowed speed for the simulation. The node goes in direction of its destination with the chosen speed. After reaching this destination point, the node stays at its location for a certain time, called pause-time. The pause-time and the maximum speed allowed for the simulation are metrics of the mobility of the nodes. In the simulator, the position of the nodes is computed at each time-slot considering their destination, their initial position, and their speed.

Propagation delay and receive-to-transmit transition time are assumed to be negligible. For any two nodes within a given transmission range R, the communication is assumed to be possible and the effects of interference and capture are not taken into account. Queues have an infinite length.

We consider N nodes generating packets of fixed length according to a Poisson process with rate λ packets per time-slot. Source and destination are randomly chosen for each packet.

Simulations are performed to study the behavior of the scheduling policy. Simulation duration is 10,000 time-slots. Input parameters are the sender density θ, the transmission range R, and the number of nodes N. Output metrics are the mean delivery delay, the throughput of the network, the queue length, and the total number of simultaneous successful transmissions per time-slot (spatial reuse of the resources in the network).

Simulation results

The first set of simulation studies the characteristics of the base line case, i.e., the two-hop strategy combined with the two-handshake MAC protocol. Finding an optimal transmission range in a mobile ad hoc network is a very important issue of the system design. Indeed, this parameter has high impact on interference, network connectivity, power consumption, or number of hops between a source and a destination. Long range communications insure a very good connectivity of the network and reduce the mean number of hops (and thus, routing overhead). However, network throughput is fundamentally limited because of the high level of interference induced by high transmitted power. As a matter of fact, best performances are reached when communications take place between nearest neighbors, as shown in [2]. With this design choice, level of interference is reduced but the mean number of hops increases and most of the packets carried by the network are relayed packets. In the scheduling policy proposed by Grossglauser and Tse in [3], the maximum allowed number of hops is two and the transmitted power is kept small, so both relaying traffic and interference are reduced. However, a small transmission range reduces the probability of finding adequately matched source and destination as well as relay nodes as and when required. Figure 4 shows that an optimal range is achieved at R~0,07m in a given network area of $1m^2$, and this value doesn’t depend on the input load.

Figure 5 shows the average number of simultaneous successful transmissions within a time-slot as a function of the transmission range ($\theta = 0,5$, $\lambda = 2$ packets/time-slot). This is a measure of the spatial reuse of the channel. This figure gives us an additional information on the influence of the number of nodes: At the optimal transmission range the throughput at the MAC sub-layer is only slightly affected by the node density. This results confirms the conclusions of [3].

In Figure 6, the influence of the sender density is shown. An optimal value is achieved approximately at $\theta = 0,3$. Simulations show also that the sender density affects the optimal transmission range. Results on the influence of the transmission range and of the sender density suggest that the maximum throughput is achieved when the probability for a receiver to have a single sender in its transmission range is maximal. In this case, the number of collisions is reduced and a maximum of communications is reached.

For the results of the Figure 7, the random way-point mobility model is used with a fixed pause-time of two time-slots. They show the influence of speed on the system performance. As expected the throughput increases as the maximum allowed speed increases. Indeed, the probability for a source of finding the destination is better.

However, the optimal transmission range is not affected by the mobility.

Simulations show that the one-hop strategy exhibits better performances than the two-hop one whereas the baseline case outperforms the three-hop strategy (see Figure 8). This result seem to contradict the conclusion of [3] that claims that better performances are achieved with relaying. In fact, traffic models are different. [3] considers that a given source generate packets for only one well determined destination whereas in this paper destinations are randomly chosen for each packet. Thus, packets for a given destination are disseminated by the traffic generators in the network and the relaying schemes (two- and three-hop) do not bring additional diversity. Instead, the relaying traffic degrades the performances of the system.

Figure 9 shows that a better throughput is achieved by using the proposed four-handshake MAC protocol. This is due to its collision avoidance mechanism and its reliability. Indeed, in the perfectly slotted environment no data packet is lost.

However, this system is not stable because the mean length of queues is continually growing as the offered load increases. Figure 10 shows the mean length of queues at each node over the simulation (10,000 time-slots).

Discussion

The proposed distributed scheduling policy is a practical way of showing that mobility can increase capacity in mobile ad hoc networks. Simulation results give rise to some concluding remarks and discussions.

The models that have been used can be improved to be more realistic. In particular, nodes are assumed to be fixed during a time-slot, so that the reliability of the four-way handshake protocol can be affected in a more realistic environment.

Proposed MAC protocols can be replaced with any other receiver-initiated MAC protocol.

As explained in [3] and [4], multi-user diversity can not be used for time-sensitive application because the delay of packets can not be guaranteed. Moreover, excessive delays suggest that the system is not stable, Figure 10 shows the increasing length of queues in nodes at the end of the simulation.

At last, the issue of synchronization has not been studied. Simulations have to be performed in an un-slotted environment.

Conclusion

In this paper, we have proposed and studied a new scheduling policy for dense and highly mobile ad hoc networks. This policy is using mobility as a source of diversity, as it has been proven that it increases the capacity of manets. Simulation results with different MAC sub-layers show that an optimal transmission range exists for such a policy. It has been shown that the throughput can be kept constant as the density of nodes is increasing. Moreover, this paper shows that non-relaying scheme can outperform a two-hop or a three-hop strategy for a certain traffic model. However, excessive delays suggest that this system is not stable.

References

[1] N. Nikaein, H. Labiod, and C. Bonnet, "DDR-Distributed Dynamic Routing Algorithm for Mobile Ad hoc Networks", *6th Annual International Conference on Mobile Computing and Networking*, MOBICOM 2000,

[2] P. Gupta and P. R. Kumar, "The Capacity of Wireless Networks", *IEEE Trans. on Information Theory*, vol. 46, pp. 388-404, Mar.2000,

[3] M. Grossglauser and D. Tse, "Mobility Increases the Capacity of Ad-hoc Wireless Networks", IEEE INFOCOM 2001, Anchorage, Alaska, Apr. 2001,

[4] R. Knopp and P. A. Humblet, "Information Capacity and Power Control in Single-Cell Multi-user Communications", *International*

Conference on Communications, ICC'95, Seattle, June 1995,

[5] D. Tse, "Multi-user Diversity in Wireless Networks", Seminar, Jan. 2001. http://degas.eecs.berkeley.edu/~dtse/pub.html,

[6] F. Talucci and M. Gerla, "MACA-BI (MACA By Invitation). A Wireless MAC Protocol for High Speed Ad hoc Networking", *6th International Conference on Universal Communications Record*, vol. 2, pp. 913-917, 1997.

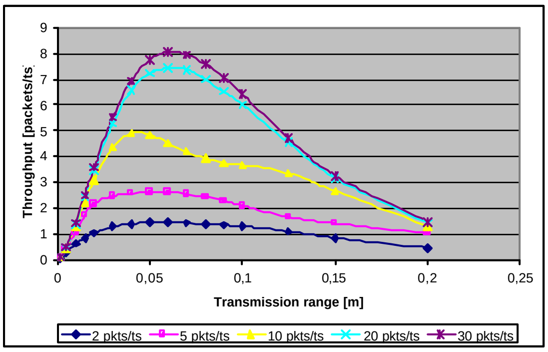

Figure 4 Throughput as a function of R and l - N = 100, q = 0,5, network area = 1m^2

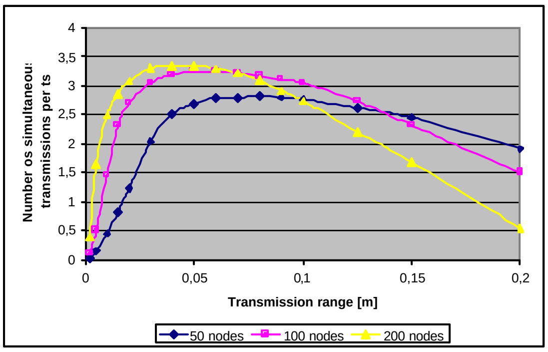

Figure 5 Influence of the number of nodes on the throughput - l = 2 packets/ts, q = 0,5, N = 100, network area = 1m^2

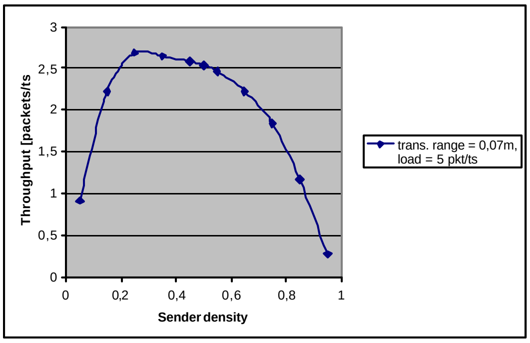

Figure 6 Throughput as a function of the sender density - l = 5 packets/ts, N = 100, R = 0,07m

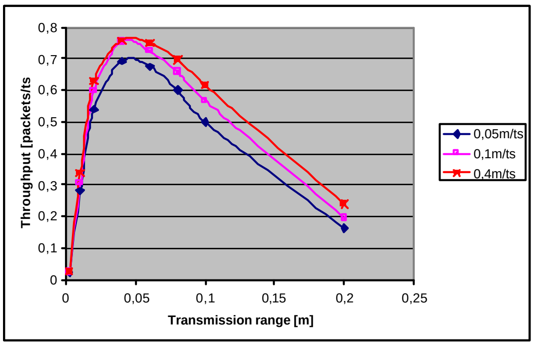

Figure 7 Influence of mobility with random way-point mobility model - l = 2 packets/ts, N = 100, q = 0,5, network area = 1m^2

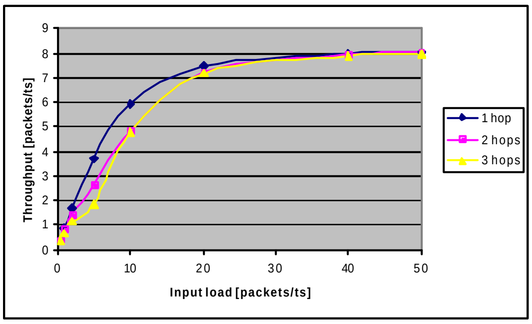

Figure 8 Influence of the hop strategy on the throughput - l = 2 packets/ts, N = 100, q = 0,5

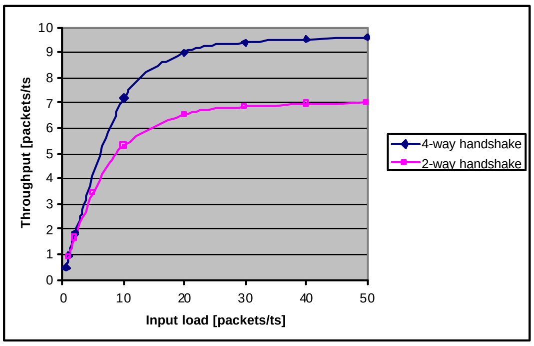

Figure 9 Two-way vs. four-way handshake MAC protocol - l = 2 packets/ts, N = 100, q = 0,5

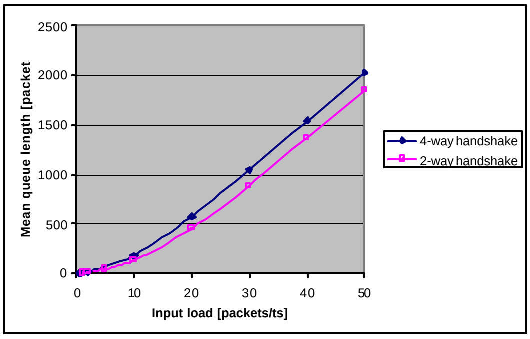

Figure 10 Mean queue length - l = 2 packets/ts, N = 100, q = 0,5