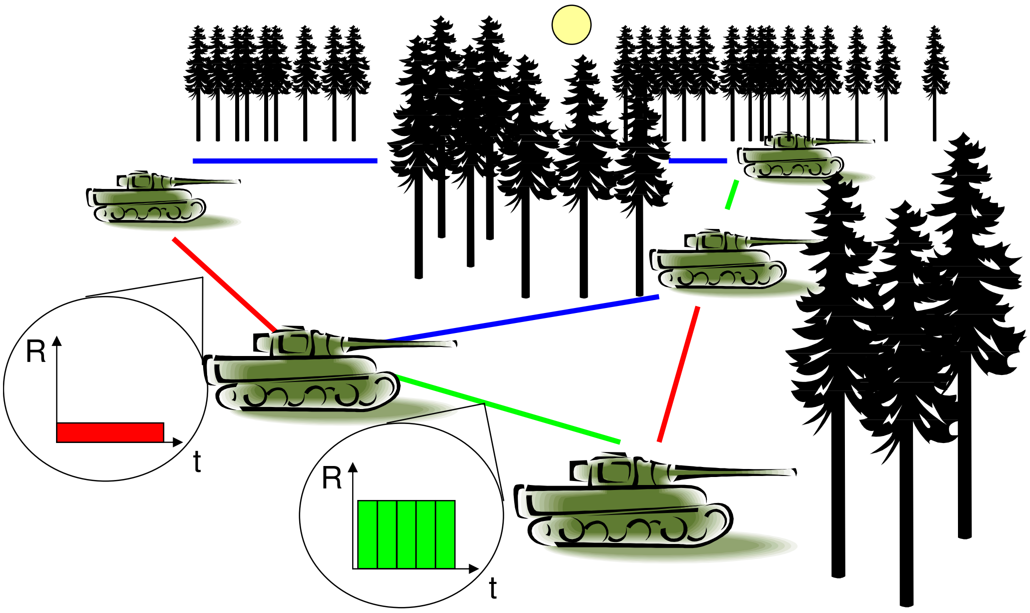
Using Variable Data Rate in Mobile Ad Hoc Networks Supporting Delay Sensitive Traffic

Linda Farman, Jan Nilsson, and
Otto Tronarp



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Abstract

In wireless ad hoc networking efficient resource management is crucial in order to deal with delay sensitive traffic. This paper presents results from studying such traffic in a mobile scenario and focuses on the gains that can be obtained by variable data rate. We study this from several points of view, the effect of lower data rates, the routing metric, and delayed routing update. The results show that the greatest benefit with adding lower data rate links is the increased connectivity in the network. Lower data rates also gives a better support when the routing information in the network is delayed. Further, the choice of routing metric is also important in order to be able to fully utilise a large range of data rates.

Keywords

ad hoc networks, variable datarate, quality of service, QoS, routing metric

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I ad hoc-nät är en effektiv styrning av resurserna viktig för att kunna handskas med fördröjningskänslig trafik. I rapporten visas resultat där denna trafiktyp används i ett mobilt scenario, med fokus på de möjliga vinster som finns med att använda variabel datatakt på länkarna. Vi studerar detta ur olika aspekter, effekten av lägre datatakter, routingmetrik och fördröjd uppdatering av routinginformationen. Resultaten visar på att den största vinsten med att använda lägre datatakter är den ökade konnektiviteten i nätet. Lägre datatakter ger även ett bättre stöd när routinginformationen är fördröjd. Även valet av routingmetrik är viktig för att ha nytta av ett stort antal olika datatakter.</td></tr>
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Chapter 1

Introduction

The unpredictable and constant changing channel conditions in mobile ad hoc networks constitute a challenge, and have to be dealt with. Adapting the data rate (alternatively also power) to the present condition is one way. However, to take full advantage of a variable data rate, the higher layers have to adapted concurrently. This becomes even more important when dealing with Quality of Service (QoS). In this report we focus on some of the challenges and benefits with having variable data rates.

The networks we consider uses traffic adaptive Time Division Multiple Access (TDMA) based access and proactive routing, where a packet is sent over the route with the best metric. Whenever the conditions for a link is changed, also the Medium Access Control (MAC) and routing are affected. The MAC may want to re-assign time slots and the routing protocol may want to send packets on another route with a better metric. However, changing the MAC and routing requires interaction with other nodes and takes time. We have decided to simplify the MAC problem and use a rather optimal MAC that can re-assign time slots in a centralized way without any delay and instead investigate the impact on the routing.

The mobility is obtained by employing a random walk mobility model. We model the delay sensitive traffic as unicast CBR flows between nodes, with a acceptable delay low enough for voice calls [1].

If the aim is to maximize the overall network throughput for traffic without any delay constraints, then it is preferable to use short high data rate links. On the other hand, if the traffic is delay sensitive, low data rate links helps avoiding network fragmentation and reducing the number of hops between the source and destination, which in turn may reduce the delay. Furthermore, the possibility to maintain a route for a longer time by reducing the data rate in a mobile scenario may be important if the re-routing is costly.

The focus in this study is to investigate variable data rate for mobile ad hoc networks. The first approach is to investigate two types of routing metrics, minimum hop and data rate based. The second approach is to compare variable data rate to fix data rate, to determine the possible gains. In particular benefits with low data rates. Finally, the third approach is to study how well variable data rate handles delayed re-routing information. The fix data rate is 1 Mbps, and the variable data rate range is from 0.25 Mbps to 8 Mbps.

In Chapter 2, we present the radio network model. The networks scenarios are described in Chapter 3, and the results in Chapter 4. Finally, in Chapter 5, we give our collusions.

Chapter 2

Radio Network Model

2.1 Link Model

An essential part of modelling an on-ground or near-ground radio network is the electromagnetic propagation characteristics due to the terrain variation. A common approach is to use the basic path-loss, L_b, between two nodes (radio units). To estimate the basic path-loss between the nodes, we use a uniform geometrical theory of diffraction (UTD) model by Holm [2]. To model the terrain profile, we use a digital terrain database. All our calculations of the basic path-loss are carried out using the wave propagation library DetVag-90® [3].

For any two nodes (v_i, v_j), where v_i is the transmitting node and $v_j \neq v_i$, we define the signal-to-noise ratio (SNR), here defined as E_b/N_0, in node v_j, Γ_{ij}, as follows

$$\Gamma_{ij} = \frac{P\, G_T(i,j)\, G_R(i,j)}{N_R\, L_b(i,j)\, R_{ij}}, \tag{2.1}$$

where P denotes the power of the transmitting node v_i (equal for all nodes), $G_T(i,j)$ the antenna gain of node v_i in the direction of node v_j, $G_R(i,j)$ the antenna gain of v_j in the direction of v_i, N_R is the receiver noise power, R_{ij} is the data rate, and $L_b(i,j)$ is the basic path-loss between nodes v_i and v_j. We assume isotropic antennas in this study.

Depending on the SNR on the link, the data rate is chosen to match the current channel conditions. The data rate is always chosen to be as high as possible according to Table 2.1, since the goal is to achieve maximum throughput. This

Table 2.1: Studied data rates and SNR for an information block size at 64 bits.

Level	Data rate	SNR (dB)
1	0.25 Mbps	1.39551
2	0.5 Mbps	1.70604
3	1 Mbps	2.32642
4	2 Mbps	3.76604
5	4 Mbps	7.00000
6	8 Mbps	15.80950

means that when the SNR on the link is low, the data rate will be low and vice versa.

2.1.1 Variable Data Rate

In this work we have used six different data rate levels, starting with 0.25 Mbps as Level 1 and ending with 8 Mbps as Level 6, see Table 2.1. The SNR used in our model correspond to an information block sizes of 64 bits and 256 bits for respectively data rate at a packet error probability of 10^{-4}, and bandwidth of 2.5 MHz. Table 2.1 shows the SNR values for the information block size of 64 bits. This information is from [4]. Since information about the lower data rates are missing, we had to extrapolate.

2.2 Medium Access Control

Carrier Sense Multiple Access (CSMA) is one of the most frequently used MAC protocols for ad hoc networks. Like most contention-based protocols, it has inherent problems with providing QoS guarantees. Another MAC protocol that is more suitable from a QoS perspective is TDMA. TDMA is a static collision-free, protocol where the channel sharing is done in the time domain. This means that the time is divided into time slots, with duration T_s, and each node is assigned one or several time slots where it is allowed to use the channel, so called MAC scheduling. In this study, the protocol is node-oriented.

However, how the scheduling is done in a mobile scenario is by itself a research area. The aim here is not to investigate how such scheduling of the

MAC protocol should be done. However, we want a schedule that adapts to the traffic and the network topology in order to study the effects of using variable data rate. Therefore, we use a rather optimal method to decide which node may use a certain slot and do not consider the required control traffic. According to this method, we determine at each time slot, which node has the oldest queued packet. This node is then allowed to use the time slot. With that the protocol is also traffic adaptive, i.e. the node is allocated time slots corresponding to the traffic load the node is exposed to. For simplicity, the slot assignment in our simulation is centralised, there are however ways to distribute the slot assignment, see [5] and [6].

The transmission time for a packet, T_p, on a link with high data rate is shorter than the transmission time of the same packet on a link with lower data rate. Depending of the data rate on the links, a node can transmit different number of packets in each time slot. To optimise the use of each time slot, as many packets as possible are sent in each time slot. The first packet sent in the time slot, p_0, is the first packet in the node's queue. If the time slot is not full the next packet in queue is transmitted if it fits. This is repeated until the time slot is full or the next packet in queue does not fit in the remaining part of the time slot. At the end of each time slot, a guard time, T_g, is inserted to avoid collisions on the channel, see Figure 2.1.

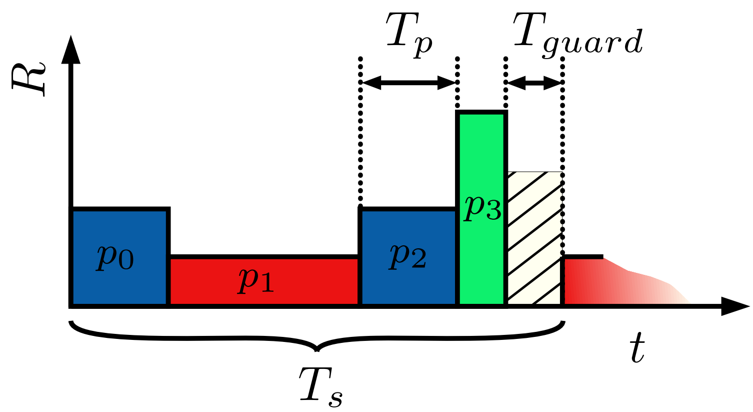

Figure 2.1: Example of transmission of multiple packets in one time slot.

If a packets transmission time T_p is larger than the available time in a slot, a packet can be split into smaller packets with a minimum size of 64 bits.

If the aim is a high maximal throughput for best effort traffic a large time slot size T_s is favourable.

A small time slot, on the other hand, has the advantage that the slots can be efficiently utilised for higher data rates if we allow for packet fragmentation. It also give a better support for short delay, since a node in average has to wait a shorter time before it is assigned the next time slot.

Clearly, a too short slot size is not efficient either. A transmission needs to include at least some packet overhead as well as a guard time to avoid collisions.

The length of a time slot is adjusted so that a packet of 256 bits precisely fit into the time slot at 1 Mbps. At the lower data rates, the packet is fragmented to fit in the time slot. Thus, for data rates higher than 1 Mbps it might be cases when parts of the time slots are empty.

2.3 Routing

We use minimum cost routing with two different cost metrics. The minimum cost routing problem is here solved with Dijkstras algorithm [7]. We study one cost metric where the cost to route over each link is one. This creates a routing table that minimise the number of hops needed to deliver a packet to its destination node, minimum-hop routing. The other cost metric is based on the data rates on the links, data rate based routing. This means that every link has a cost that is inversely proportional to the data rate on the link. This creates a routing table that minimise the sum of the cost for the route from the source to the destination node.

Further, we also study the case of introducing a global delay when updating the routing information in the nodes. This means that each node has a current and correct information about the links to its neighbours, local information, but the link information for the entire network, global information, is delayed a specified time. Thus, we have two type of regions, N local regions for each node with updated information and one global with delayed information. Each node merges its local information, with the global delayed information for nodes further away, and use that merged information when it routes a packet.

2.4 Traffic Model

The traffic is modelled as unicast sessions with Constant Bit Rate (CBR) flows. The idea is to model a simplified model of unicast voice call between nodes. We assume that new sessions start according to a Poisson process and that they have an exponential distributed duration with a mean call duration of 12 seconds. Furthermore, we assume that the traffic is uniformly distributed over the nodes, i.e. each node is equally probable as the source node and each node except the source node is equally probable as the destination node.

During a session, the source is assumed to transmit packets to the destination with a constant bite rate, 12,2 kbps, and with constant packet size, 256 bits. Thus, it models point-to-point traffic and one way connections. These parameters are similar to the GSM standard (Enhanced Full Rate) [8]. To model a delay sensitive traffic we have a maximum acceptable delay on the packets, chosen to 150 ms as recommended by ITU [1], which is small enough to carry speech. Further, the session is considered failed if more than 5 % of the packets are delayed more than 150 ms during the session. We also study the case with traffic modelled as CBR flows, but without the delay constraint.

Chapter 3

Network Scenarios

The sample network studied consist of 40 nodes. We study mobile networks, employing a random walk mobility model, where the nodes have a speed of 20 m/s. The scenario is that the nodes moves around randomly for 2000 seconds in an area of 1 km^2. The area is located in south-east of Sweden, where the most part of the terrain is rather hilly and covered by forests. This scenario is then simulated for each traffic load, i.e. we start with the lowest traffic load and simulate for 2000 seconds and then continues with the next traffic load and so on until we have simulated the highest traffic load. Thus, the same scenario is repeated for each traffic load.

Let N be the number of nodes, then there are $N(N-1)$ possible point-to-point connections, either single hop or multihop between nodes. However, not all connections may exist. Connectivity is measured as the fraction of existing point-to-point connections and averaged over a simulation run. Whenever the connectivity is 100% all nodes can reach each other through multihop during the whole simulation. The studied sample network has a connectivity of 98% when there are only 1 Mbps links in the network. When data rates lower than 1 Mbps are added to the network, the connectivity increases. To remove this connectivity increase, lower data rate links are only added to the network if the point-to-point connection existed in the (original) network with only data rates at 1 Mbps. Thus, we have two types of sample networks, one with 98% connectivity and one with increased connectivity.

Furthermore, the power, P, of all the transmitting nodes, are chosen to achieve the wanted connectivity at the data rate 1 Mbps.

Chapter 4

Results

When evaluating the results, the success rate at different traffic loads, i.e. different average number of CBR flows, are studied. The success rate is given in percent, and is defined as the percentage of successful CBR flows during a simulation run.

4.1 Routing Metrics

There are a number of things to consider when selecting the routing metric and the size of the time slot; used data rates, traffic load, and type of traffic (best effort or delay sensitive).

A long time slot, T_s, is favourable if the aim is a high maximum throughput, i.e. the highest traffic load such that the end-to-end delay is bounded, for best effort traffic. On the other hand, for a lightly loaded network only part of the long time slot may be utilised. This is due to that when there is only one packet in the node and the packet can be transmitted at a high data rate, the time slot is partly empty. Consider the following simple example:

Example: To reach the destination a packet has to be forwarded either on a one hop route with a data rate of 1 Mbps, alternatively on a two hop route, each hop with a data rate of 2 Mbps. According to the routing metric, inversely proportionally to the rate, these two routes are equivalent.

Assume that a packet fits into a time slot at 1 Mbps. Then the one hop

route is preferable at light loads. The two hop route consumes twice the number of time slots and for that time the surrounding nodes are blocked to transmit. However, at heavy load this advantage disappears and the two routes becomes equally efficient. The time slots for the two hop route can most likely be filled with other traffic.
Instead assume a shorter time slot such that a packet fits into a time slot at 2 Mbps. Then the two routes are equally efficient also at light loads, since they occupy the same number of time slots and network resources, independent of the network load.

This example illustrates that at light network loads there are cases when using high data rates in fact can reduce performance, or more correctly, due to the routing metric and that we have to fix a time slot size we can get this result. This suggests that for light load a minimum-hop routing could give a somewhat better result. However, in the simulations we have not found any differences in the success rate using the two metrics at light loads, compare Figure 4.1 to Figure 4.2.

At high traffic loads the data rate based routing is clearly better compared to minimum-hop routing. This is due to that the high data rate links are used more often/efficiently. This is shown comparing Figure 4.1 and Figure 4.2.

The conclusion is that the data rate based routing works satisfactory, even if there is room for improvements. More advanced methods involving joint scheduling and routing has also been proposed [9]. Such methods may be feasible in a static network but it is questionable if they will work in the mobile case. For static networks routing metrics for variable data rates are investigated in [10].

4.2 Benefits with Variable Data Rate

At a low average number of CBR flows, the success rate is nearly one when lower data rates are used, i.e. from 0.25 Mbps to 0.5 Mbps, see Figure 4.1. When data rates from 1 Mbps and higher are used, the success rate are noticeable lower for lower traffic loads, i.e. lower average number of CBR flows. This is also the same for data rate based routing, see Figure 4.2. However, when the traffic load

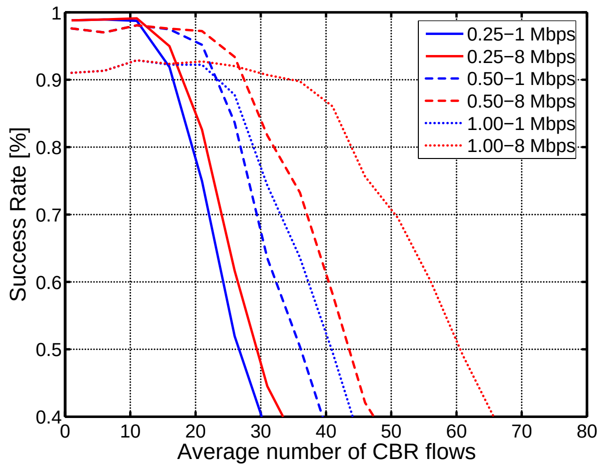

Figure 4.1: A increased connectivity network with minimum-hop routing. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps.

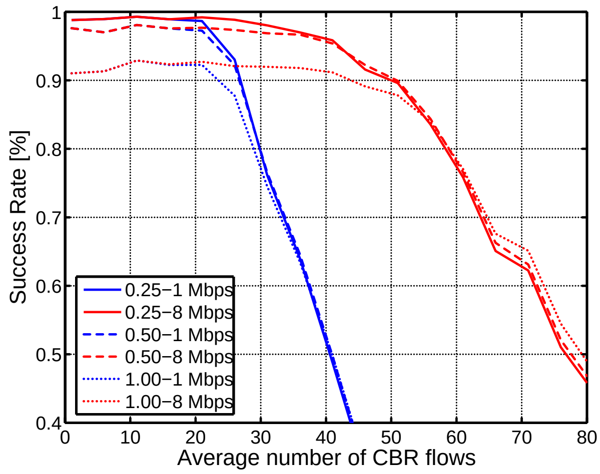

Figure 4.2: A increased connectivity network with data rate based routing. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps.

increases the benefit of using lower data rates disappears for the case of data rate based routing, and for the case with minimum-hop routing it is even better not to use the lower data rates.

To answer the question if the increase in success rate at lower traffic loads depends only on the connectivity increase, we also studied the case when we removed the connectivity increase and retained the connectivity at 98%. At this connectivity the use of lower data rates are much lower compared to the case with increased connectivity. The results, for the connectivity at 98%, show that the increase in success rate completely disappears, compare Figure 4.1 to Figure 4.3 and Figure 4.2 to Figure 4.4. For this case it is clear that the increase in success rate is only due to the increased connectivity in the network.

For this case, the only benefit with using lower data rates is the increase in connectivity in the network. Further, an increase in connectivity also means that more users have to share the same resources in the network, which can be a loss in terms of total throughput for some users, but a gain in terms of fairness in the network.

Important is also the possibility to maintain a route in the routing table for a longer time when using variable data rate compared to the case when having just one fix data rate. If a route can be used for a longer time, the changes of the network topology decreases, and with that the consumed resources for rerouting.

4.2.1 The Delay Constraint

In Table 4.1 the different maximum throughput for CBR traffic (D-CBR) and CBR traffic without the delay constraint are shown. The maximum throughput for the delay sensitive CBR traffic corresponds to a success rate at 78% for minimum-hop routing and a success rate at 88% for data rate based routing. The loss in throughput due to the delay constraint is about 50% for minimum-hop routing and about 24% for data rate based routing. This indicate that it is much more costly to support delay sensitive traffic, than traffic without the demand on delay. It also shows that it is important to use data rate based routing instead of minimum-hop routing, to support delay sensitive traffic.

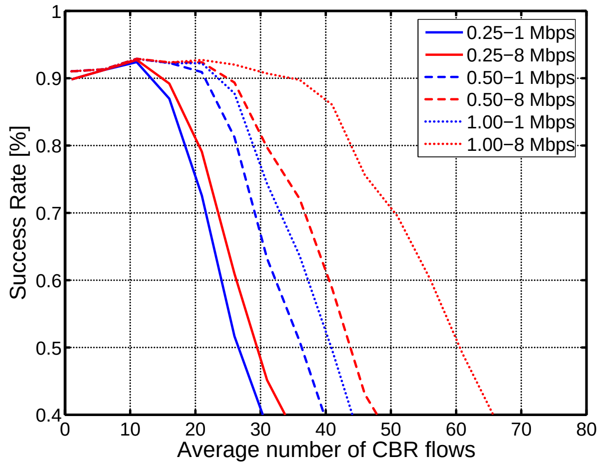

Figure 4.3: A 98% connectivity network with minimum-hop routing. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps.

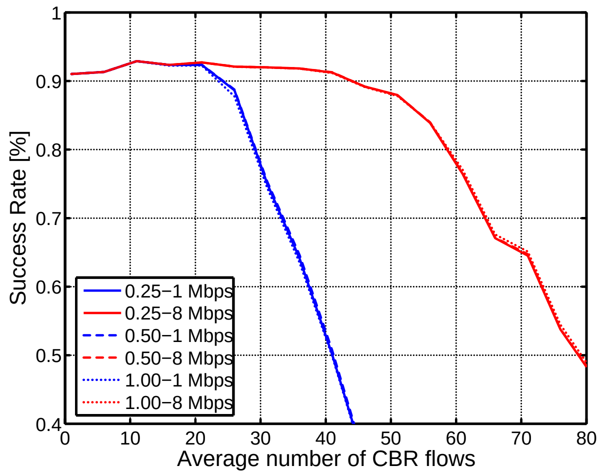

Figure 4.4: A 98% connectivity network with data rate based routing. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps.

Table 4.1: Maximum throughput for CBR traffic with and without the delay constraint, D-CBR respectively CBR (best effort), for 0.25-8 Mbps.

	CBR	D-CBR	Relation
$1/R$	678.0 kbps	516.9 kbps	0.76
min hop	328.0 kbps	175.3 kbps	0.53

4.3 Delayed Routing Update

In Figure 4.5 and 4.6 the performance degradation when the routing update is delayed up to 4 s is illustrated. The connectivity is 98 % at 1 Mbps.

Adding data rates below 1 Mbps is beneficial when we use a data rate based routing metric, as can be seen in Figure 4.5. Adding 0.5 Mbps links give some improvement, when we go from using 1 Mbps to using 0.5-1 Mbps we see a 10 percentage point increase of the success rate for a delay of 2 s. Whereas adding also 0.25 Mbps gives a negligible additional improvement for small delays.

Adding and using higher data rates, as in Figure 4.5, is not to recommend when the route update delay is long. Using high data rates results in more hops to reach the destination and this also requires a good topology knowledge. If this is not the case the long routes can be out of date and packets can be routed in loops.

If we instead use a minimum-hop metric as in Figure 4.6 and add data rates below 1 Mbps we get a initial performance penalty at low delays. However, the performance is almost unaffected when the delay increases.

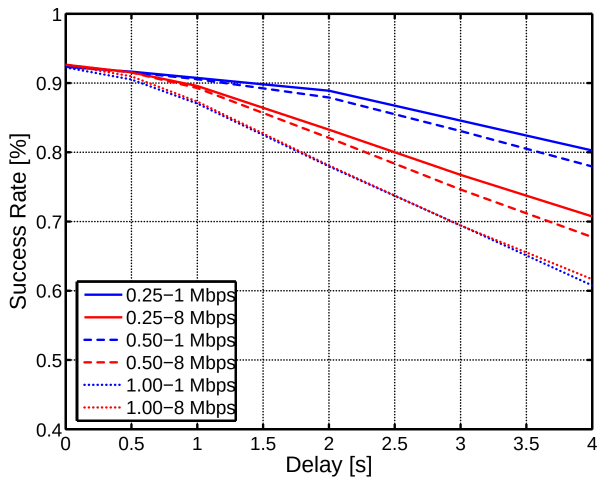

Figure 4.5: A 98% connectivity network with data rate based routing for routing update delays from 0 s to 4 s. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps. The success rate corresponds to at average 20 number of CBR flows.

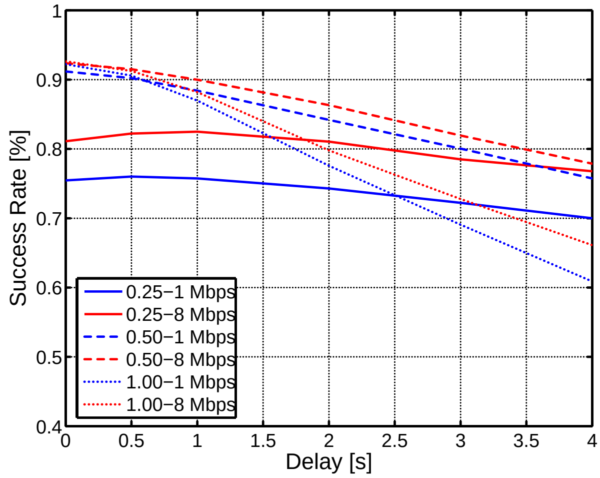

Figure 4.6: A 98% connectivity network with minimum-hop routing for routing update delays from 0 s to 4 s. Data rate combinations: 0.25-1 Mbps, 0.5-1 Mbps, 0.25-8 Mbps, 0.5-8 Mbps and 1 Mbps. The success rate corresponds to at average 20 number of CBR flows.

Chapter 5

Conclusions

This report investigates issues concerning using variable data rate in mobile ad hoc networks supporting delay sensitive traffic. Firstly, the routing metric is considered, to see if a minimum-hop metric is usable, or even to prefer over a data rate based metric. We show that the minimum-hop metric never gives a better result in terms of success rate at a given traffic load, even at very light traffic loads. On the other hand, even though the success rate is not better for the minimum-hop routing, this routing is more tolerant towards long delays in updating the routing information. Thus, to take advantage of high data rate links the data rate based routing is needed, and it gives a considerably better result at high traffic loads. The drawback is that the data rate based routing needs much more accurate routing information, compared to the minimum-hop routing.

When considering adding low data rate links, it is the data rate that gives a fully connected network that is important. Using links with even lower data rates does not give any further noticeable improvement. The exception is when we have long delays of the routing updates, here using such lower data rates gives some improvements.

Using very high data rate links is not straightforward either, and do not necessarily contribute to a better overall performance. It is likely that the time slot is partly empty. This is avoided for maximum load (full queues), but then we cannot support delay sensitive traffic. In the cases investigated, compared to using only 1 Mbps, roughly twice the number of CBR flows can be supported by using the four rates 1, 2, 4, and 8 Mbps.

It is clear that having the possibility to use variable data rate is an advantage. Moreover, to fully utilise the potential of a large range of data rates the routing and MAC interaction become very important. For example, by aggregating traffic over high data rate links it can be avoided that time slots are partly empty.

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