Link Adaptation Feedback Interval for Narrowband Mobile Ad-hoc Networks in Disaster Search and Rescue Scenarios

S. Helmle[#], M. Dehm[#], M. Kuhn[#], and D. Pesch*

[#] Institute of Telecommunications, University of Applied Sciences Darmstadt,
Darmstadt, Germany
* Nimbus Research Centre, Cork Institute of Technology, Cork, Ireland
e-mail: helmle@ieee.org

Abstract

Mobile ad-hoc networks (MANETs) enable operation without fixed infrastructure, making them attractive for disaster search and rescue (SAR) and tactical applications. Reliability is an issue in such applications and increasing MANET communication reliability is critical for the acceptance of these systems. In this paper we investigate the impact of feedback delay on adaptive modulation and coding (AMC) in VHF narrowband MANETs. We analyse communication reliability and quality of service (QoS) under realistic conditions and study user net throughput for various AMC feedback delays. Results from Monte Carlo computer simulation show that a global maximum for the throughput with respect to the feedback interval exists. The achievable throughput, however, strongly depends on the user mobility pattern.

Keywords

Wireless communication, mobile ad-hoc networks, narrowband, adaptive coding

1. Introduction

The vision of infrastructure-less communications with mobile ad-hoc networks (MANETs), which are able to provide communication services in a constantly changing network topology, has motivated considerable research effort over the past two decades. The advent of small, portable communication devices like personal digital assistants (PDAs), smartphones and tablets, and wearable computers is offering the potential to make this vision come true for application areas where

1. only sparse or no infrastructure is provided,
2. nodes join, leave, and re-join the network by intention, due to mobility, or due to adverse effects of the radio channel,
3. and/or nodes are both concentrated at one location and sparsely distributed in other regions.

Applications such as disaster search and rescue (SAR) missions and tactical communications can use MANETs to establish and maintain connections between nodes as MANETs can operate in such conditions by adapting transmission parameters according to the changing network topology. However, while adaptation mechanisms such as adaptive modulation and coding (AMC) can significantly improve network performance, the deployment of these techniques is relatively complex in networks with completely distributed management. Especially in networks with strong bandwidth limitations as investigated herein, the difficulty of increasing overhead emerges, requiring effective parameter adaptation in MANETs.

The subject of this paper is the investigation of the impact of feedback interval on AMC in time division multiple access (TDMA)-based single-carrier very high frequency (VHF) narrowband (bandwidth of 25 kHz) MANETs. For the link adaptation mechanism adaptive modulation and coding (AMC) is utilised where channel state feedback packets are transmitted from a receiver back to a transmitter. AMC is investigated at system level using an abstract model for the radio channel, with a delay spread of τ_{rms}=14.5 µs. Since the MANET studied in this paper targets applications where bandwidth is strongly limited to enable large single-hop coverage (e.g. military communications or disaster search and rescue operations) minimisation of signalling overhead (used for link adaptation) is of major importance and is one of the most challenging issues to date. In this context, previous work (Helmle et al., 2013) focusing on the characterisation of link adaptation feedback has shown that the phenomenon of a constant AMC feedback delay (e.g. due to queuing issues) of up to ten cycles remains more a theoretical issue rather than a practical challenge. Hence, limited feedback remains beneficial for link adaptation. Despite the fact that only single-hop transmissions are analysed, our findings can also be beneficial for quality of service (QoS) provisioning in (TDMA-based) multi-hop wireless radio communication systems employing AMC.

The remainder of this paper is organised as follows: Section 2 presents related work. The system model used in our study is described in Section 3. In Section 4 the simulation model and parameters as well as the results are presented. Finally, Section 5 concludes the paper.

2. Related work

To mitigate multi-path fading impairments in two-hop MANET scenarios, adaptive modulation and coding can be applied as shown in (Müller and Hong, 2010). The combination of AMC and multi-hop transmission can achieve a trade-off between network coverage and throughput. The authors of (Müller and Hong, 2010) provide a mathematical performance evaluation for two-hop connections (source - relay - destination). In 2008, Cho et al. investigated multi-hop networks for multicast broadcast services in mobile WiMAX systems (Cho et al., 2008). For the optimisation of throughput, an AMC scheme was adopted in order to perform appropriate selection of modulation and coding schemes (MCS) between base station and relay station. As shown from computer simulations, the application of AMC to multi-hop networks with (fixed) infrastructure can yield significant performance improvements. In (Helmle et al., 2012) the impact of link adaptation in frequency-selective wireless multi-hop ad-hoc networks was investigated with respect to the average end-to-end throughput and delay. Here, only scenarios without mobility were considered. The benefits of using AMC were shown for both AWGN and DAB channel conditions. The results confirmed the suitability of AMC in trading throughput for coverage in multi-hop networks. However, the performance of a closed loop AMC system significantly depends on the thresholds for the modulation and coding schemes applied. Zheng et al. analysed the impact of AMC adjustment period in mobile satellite communications environments (Zheng et al., 2012) and found that the application of AMC can improve the performance. However, they showed that for longer AMC adjustment periods the performance improvement will be less obvious. (Döttling et al., 2004) evaluated the performance of channel quality feedback (CQF) schemes for High-Speed Downlink Packet Access (HSDPA) using FDD. Overall, they found that CQF schemes, considering data packets which are transmitted as bursts, enable notably higher efficiency compared to a cyclic AMC feedback. Furthermore, they mentioned that reducing the overhead caused by CQF saves power and mitigates interference.

As shown here, studies investigating link adaptation feedback exist. However, the majority of the related work does not deal explicitly with QoS from the AMC point of view, i.e. how the specific operation of resource reservation and assignment, etc. affect AMC performance. In most cases the underlying system models differ from the boundary conditions we consider here, e.g. narrowband channel, VHF radio, etc. For example, in satellite communication high propagation delays and low SNR at the receiver need to be considered whereas shadow fading is in general not a major impact factor except in cities with dense and high buildings. Mobile radio networks like UMTS achieve coverage by employing a cellular system with frequency reuse that leads to substantially higher user bandwidths (multiple MHz) compared to our narrowband VHF system. Since they are centrally organised (using base stations) only single-hop transmissions occur. This paper contributes results from performance evaluation of AMC feedback delay in narrowband MANETs operating in the VHF frequency band and QoS requirements to guarantee an AMC based on feedback information achieves reliably good performance.

3. System model

The system model is based on a single-carrier VHF narrowband MANET consisting of two nodes. One is the transmitter, which emits data packets and the other is the receiver receiving data packets. Fig. 1 shows the two scenarios covered by this study reflecting typical mobility pattern during SAR missions. A constant bit rate multicast voice service capable of reaching the majority of mobile receivers within a single hop is the primary service. The secondary service is a variable bit rate background data service. At the application layer traffic is generated continuously at the maximum achievable data rate. For low data rates at least the multicast voice service is transmitted. Whenever the data rate available is sufficient, the background data service will be transmitted in addition to the multicast voice service via piggybacking.

(a) Pass (b) Circular

Figure 1: Overview of simulation scenarios. (O, Δ) denote transmitter and receiver, respectively.

The present system model does not consider re-transmissions at the link layer, therefore, the calculated throughput is the net amount of data rate available for a transparent data service. The system uses TDMA with a superframe structure as per Fig. 2 to manage channel access. A superframe consists of M+1 frames whereby M depends on the feedback interval. Since the ability to establish either three quasi-parallel single-hop channels or at least one multi-hop (up to three hops) channel is required, each frame consists of three slots. The slot duration is designed to accommodate multicast voice packets even when the most robust modulation and coding scheme (MCS) is applied. To avoid asynchrony between application layer and link layer, the TDMA frame duration is equal to the inter-departure rate of the multicast voice service as in other voice-driven systems like GSM.

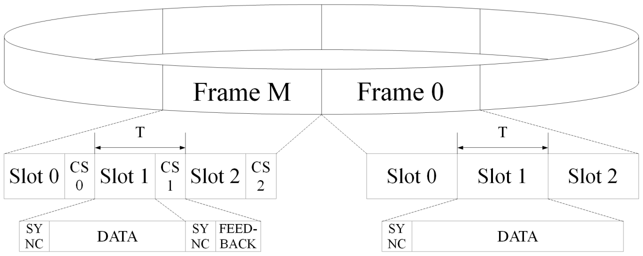

Figure 2: TDMA superframe structure consisting of M+1 frames. Frames 0 to M-1 accommodate data slots only while frame M consists of both data slots and control mini-slots (CS) for AMC feedback.

Only once within a superframe, i.e. in frame M each slot is followed by a short control minislot to enable a transmission of AMC feedback as well as other control data. A short AMC feedback packet will be transmitted by the receiver for a data packet received in frame M of which at least the header has been received correctly. Upon receipt of the AMC feedback, the transmitter is able to determine which MCS is the best for the next superframe period. While the MCS for the data transmitted in regular slots is variable, AMC feedback is always transmitted using the most robust MCS.

In order to select respective MCSs, a link adaptation algorithm based on signal-to-noise ratio (SNR) measurements is applied. Thresholds for the MCSs are selected in order to achieve a packet error rate (PER) of less than 0.01, which is required for real time applications such as voice services where retransmissions cannot be applied. The SNR may be obtained either by a channel estimation via the SYNC sequence or by computing the error vector magnitude (EVM) subsequent to the equalisation process. The MCSs considered in this work are presented in Table 1. It should be noted that the bit rate for each MCS represents the user net bit rate (i.e. with regard to the case where a frame consists of data slots only) offered to the application layer.

ID	MCS	Bit rate/kbit/s	ID	MCS	Bit rate/kbit/s
0	BPSK 1/2	2.89	7	16-QAM 1/2	12.43
1	BPSK 2/3	3.94	8	16-QAM 2/3	16.65
2	BPSK 3/4	4.46	9	16-QAM 3/4	18.76
3	QPSK 1/2	6.09	10	16-QAM 5/6	20.87
4	QPSK 2/3	8.21	11	64-QAM 2/3	25.09
5	QPSK 3/4	9.26	12	64-QAM 3/4	28.26
6	QPSK 5/6	10.32	13	64-QAM 5/6	31.43

Table 1: Modulation and coding schemes used in link adaptation algorithm

The physical layer is simulated in a detailed link level simulation where look-up tables are generated that associate SNR with PER. The link layer simulation is able to consider effects such as Doppler spread, multipath propagation, synchronisation, frequency offset, channel estimation and equalisation as well as filtering and oversampling aspects (Dehm et al., 2012). A channel with an exponential delay power profile and a propagation delay of 100 μs (i.e. a delay spread of 14.5 μs) applies as it was found that multipaths up to 100 μs may occur in the VHF band. Signals are affected by a distance-dependent path loss as presented in the work of (Li and Kunz, 2009)

$$\gamma\left(d\left(t\right)\right)=\alpha\left(d_0\right)+\eta\log\left(\frac{d\left(t\right)}{d_0}\right)+\theta,$$

where $d\left(t\right)$ represents the separation of the source and destination node at time t, $\alpha\left(d_0\right)$ is the mean path loss at a given reference distance d_0 in the far-field of the transmitting node antenna, and η denotes the path loss exponent. The path loss also consists of fading due to shadowing and is represented by θ (Helmle et al., 2013). Shadowing is modelled as a zero mean spatially correlated log-normal process to consider influences from buildings, hills, etc. which are exploited by the link

4. Numerical results

The most important parameters used in the Monte Carlo simulation are presented in Table 2. Hereby, several parameters relating to the radio channel and the physical layer have been taken from (Li and Kunz, 2009) as they are results from field measurements.

Parameter	Setting	Parameter	Setting
Path loss exponent	4.25	System bandwidth	25 kHz
Reference distance	100 m	Noise figure	6 dB
Atten. at reference distance	71.3 dB	Frame duration	180 ms
Std. dev. shadowing	5.12 dB	Slot duration	{60,52} ms
Decorrelation distance	20 m	Minislot duration	8 ms
Transmission power	30 dBm	Voice coder bit rate	2.4 kbit/s
Carrier frequency	57.0 MHz	Inter-departure time	180 ms

Table 2: Simulation parameters

The results presented for average user net throughput at the application layer consider both, the bits transmitted for the multicast voice service and for the background data service. Fig. 3 presents the average user net throughput versus AMC feedback interval for the scenario where the transmitter is passing the receiver (cf. Fig. 1a). Hereby the abscissa represents the period in terms of TDMA frames after which an AMC feedback packet is transmitted by the receiver. In this scenario the MCS applied initially is MCS number *0* (cf. Table 1) which is the most robust MCS. For an AMC feedback interval of one frame an average user net throughput of about 20.17 kbit/s is achieved for the entire range of the transmitters' velocity. Since the structure of the TDMA superframe enables the opportunity to establish three quasi-parallel single-hop data streams (cf. Fig. 2), the transmitter emits its signals only in slot number *0*.

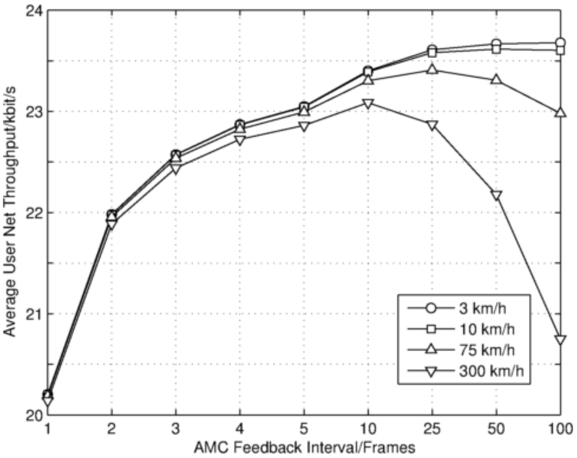

Figure 3: Average user net throughput versus AMC feedback interval for pass scenario.

Therefore, the user net throughput corresponds to about one third of the system net throughput depending on the AMC feedback interval. As the AMC feedback interval increases the average user net throughput increases, too. However, for each value of the transmitter's velocity a global maximum exists. As the feedback interval is increased beyond this maximum throughput drops. This behaviour can be explained as follows: Increasing the AMC feedback interval is leading to a reduction in accuracy of MCS selection on one hand but also a reduction of signalling overhead and hence, a reduction in signalling overhead resulting in additional user data rate on the other hand. However, as the inaccuracy exceeds a certain value (which depends on the transmitter's velocity) the probability that an inappropriate MCSs is selected increases significantly, which in turn leads to an increasing probability of packet errors and therefore a decreasing user net throughput. At this point it should be noted that an increasing AMC feedback interval also increases the probability that the current MCS is used for a longer period as the link adaptation algorithm is able to change the MCS only when an AMC feedback packet has been received or a timeout has occurred. As MCS number *0* is used initially the probability that a more robust MCS applies for a longer period also increases.

The graph in Fig. 4 shows the average user net throughput versus AMC feedback interval for the circular scenario (cf. Fig. 1b). Here, the distance-dependent path loss is constant and therefore the link adaptation algorithm adapts according to the spatially correlated shadowing loss only.

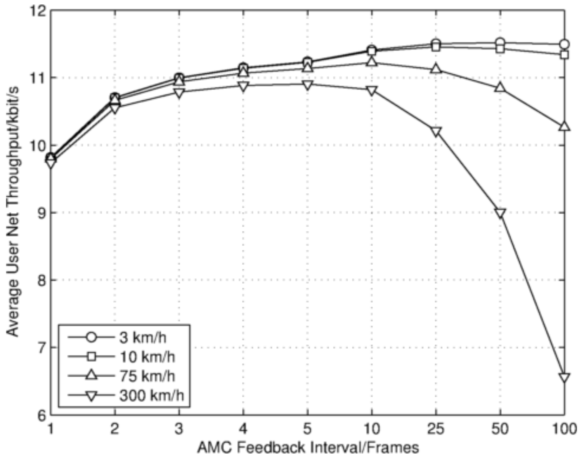

Figure 4: Average user net throughput versus AMC feedback interval for circular scenario.

As evident from Fig. 4, the qualitative behaviour is similar to the passing scenario as here the most robust MCS is chosen in the initial state. However, the average user net throughput is decreased to about 50 per cent compared to the passing scenario (cf. Fig. 3). This is due to the fact that the distance-dependent path loss remains constant (i.e. the transmitter and receiver are separated by the reference distance of 100 m) and very good channel conditions do not exists in order to select a higher order MCS.

5. Conclusions

This paper has studied the impact of link adaptation feedback interval on throughput in TDMA-based narrowband VHF mobile ad-hoc networks. The main finding is that the optimum value for feedback interval strongly depends on the nodes' velocity as well as mobility pattern. It has been shown, in case adaptive modulation and coding is employed for link adaptation, a global optimum for user net throughput may be achieved by adjusting the feedback interval, i.e. by trading accuracy of channel state feedback against a reduction of signalling overhead. For systems with the same design but different numerical parameter values, an identical qualitative behaviour may be expected. These insights may be beneficial specifically for the provisioning of narrowband systems as the trade-off between overhead and system throughput is one of the most challenging issues. Finally, in order to limit system complexity, the number of modulation and coding schemes supported by a real system is expected to be substantial lower.

6. References

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