Multi-rate Support for Network-Wide Broadcasting in MANETs*

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Abstract. Mobile ad-hoc networks (MANETs) utilize broadcast channels, where wireless transmissions occur from one user to many others. In a broadcast channel the same transmission can lead to different information rates to different users depending on the channel capacity between the transmitter and receiver pair. According to coding theory, there is a certain channel capacity that limits the rate of information that can be sent through the channel. Thus, different channel capacities result in different acceptable rates for the users. In this paper, we utilize a superposed coding scheme in a MANET scenario to provide different rates for users with different channel capacities using a single broadcast transmission. We have created techniques to extend this multi-rate concept to network-wide broadcasting scenarios, providing the ability for nodes to appropriately trade-off delay vs. quality. We describe our approach and provide simulation results showing the benefits and limitations of superposed coding in network-wide broadcasting.

1 Introduction

For broadcast transmissions, the capacities of the communication links from the source to the intended recipients vary greatly due to differences in communication range, fading, and interference on these links. Therefore, it is crucial to explore the characteristics of the broadcast channel that can be utilized to improve the throughput of the network [1].

Due to differences in qualities of the links between a broadcasting source node and the intended recipients, it is advantageous to adjust the transmission scheme for broadcasting data so that a single transmission can be best received at all receivers. In other words, with a single transmission, the nodes with "high quality" links receive "high rate" information whereas the nodes with "low quality" links receive "low rate" information. This multi-rate broadcasting can be achieved by using Cover's theory of superposed information [1,2].

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We investigate the performance gains achievable using multi-rate broadcasting for network-wide broadcasting in MANETs. For example, if we combine multi-rate transmission with scalable voice or video coding [3], nodes with different link qualities will have different rates (qualities) of voice or video available through a single transmission. To demonstrate all the benefits of multi-rate network-wide broadcasting, we utilized the NB-TRACE architecture [4], which is an energy-efficient cross-layer network-wide voice broadcasting architecture for mobile ad hoc networks. Furthermore, we also present results using Flooding with IEEE 802.11 with multi-rate broadcasting for comparison.

2 Superposed Coding

The idea of superposed coding is to add additional coding on top of the initial coding in such a way that it is unlikely that the additional information can be decoded by any receiver with a poor channel. However, any receiver with a good channel will be able to decode both the first and the second displacements of the codewords. Cover proved that the degradation in the rate for the poor channel caused by this additional displacement will allow a more rewarding increase in the rate for the good channel [1].

In Figure 1(a), the idea of superposed coding is achieved by transforming a BPSK constellation into nonuniform quadrature amplitude modulation (QAM). For a given constellation point, Figure 1(a) illustrates the noise margins, d_1 and d_2, for low rate and additional information, respectively. The nonuniform spacing makes it much easier for a receiver to correctly recover the low rate information (first bit) than the additional information (second bit). In this way, we simultaneously send two bits using a single transmission and offer two different rates of broadcasting, which potentially may lead to doubled link throughput for nodes with good channels. Note that this example can be easily extended to provide more than two levels of superposed information.

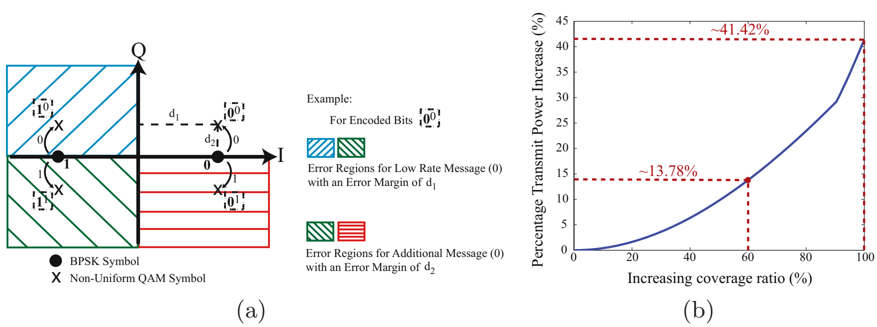
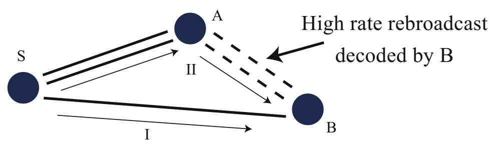


Fig. 1. (a) Constellation diagram for non-uniform quadrature amplitude modulation (QAM). The noise margins and error regions for the selected symbol are also illustrated. (b) Increase in the transmission power with increasing additional rate coverage while keeping the low-rate coverage constant.

Achieving multi-rate broadcasting without degrading the performance for the receiver with a poor channel requires an increase in the transmission power. For non-uniform QAM, the amount of extra power needed with increasing additional rate coverage is plotted in Figure 1(b). According to the plot, to introduce an additional rate coverage that is 60% of the low-rate coverage, we need to increase the initial transmission power by approximately 13.78%. When we reach equal noise margins for both rates, the constellation becomes that of uniform QAM, and this is the theoretical limit for the superposed information concept.

3 Multi-rate Network-Wide Broadcasting

Figure 2(a) shows an example where node B can receive low rate information with low delay directly from the source node S (flow I) or high rate information with high delay rebroadcast from node A (flow II).



(a)

	S	A	B
T_1	$P_{L1} \mid P_{A1}$		
R_1		$P_{L1} \mid P_{A1}$	P_{L1}
T_2	$P_{L2} \mid P_{A2}$	$P_{L1} \mid P_{A1}$	P_{L1}
R_2		$P_{L2} \mid P_{A2}$	$P_{L1} \mid P_{A1}$ & P_{L2}
T_3	$P_{L3} \mid P_{A3}$	$P_{L2} \mid P_{A2}$	$P_{L1} \mid P_{A1}$
⋮			

(b)

Fig. 2. (a) Two different rates of information available at node B: flow I, low rate information and flow II, high rate information. (b) Packet transmission and reception schedule.

This idea is illustrated in Figure 2(b) as well. At time T_1 the source node transmits the first superposed high rate packet $P_{L_1}|P_{A_1}$ consisting of the low rate information packet P_{L_1} superposed with the additional rate information packet P_{A_1}. The row starting with R_1 shows the packets received (*i.e.,* decoded) by nodes A and B. Node A decodes both the low rate and the additional information, while node B, having a bad link with S, decodes only the low rate part of the superposed packet. The next set of transmissions takes place at time T_2. At this time S broadcasts the next superposed high rate packet $P_{L_2}|P_{A_2}$. At the same time, nodes A and B rebroadcast their previously received packets $P_{L_1}|P_{A_1}$ and P_{L_1}, respectively. As can be see from the next row of Figure 2(b), node B has both rates of information available and can choose either of the flows (I or II in Figure 2(a)) according to its delay-throughput requirements.

4 Simulations and Conclusions

In this paper we extended the functionality of NB-TRACE to multi-rate data broadcasting by utilizing the cross-layer properties of the TRACE family of protocols [4]. We also modified IEEE 802.11 to include support for multi-rate

Table 1. Simulation Parameters and Setup

(a) Simulation Setup

Parameter	Value
Number of Nodes	256
Simulation Area	1000m x 1000m
Simulation Time	100s
Coverage Ratio	60%
Number of Repetitions	5
Node Mobility	Way-Point

(b) Simulation Parameters

Acronym & Description	Value
T_{SF} - Superframe duration	61.5ms
N_F - Number of frames	7
N_{DS} - Number of data slots per frame	14
N_C - Number of cont. slots per frame	15
N/A - Data packet size	110B
T_{VF} - Voice packet generation period	61.5ms

Table 2. Packet Delivery Ratios (PDRs), Packet Delay and Delay Jitter, and Energy Consumption values sorted in pairs. I: Priority Delay. II: Priority Throughput (results in doubled throughput since all nodes forward high-rate packets that have twice as much information as the low rate packets).

Architecture	PDR I	PDR II	Packet Delay & Jitter I	Packet Delay & Jitter II	Energy Use I	Energy Use II
NB-TRACE	99.6% 99.2% (min)	99.4% 97.7% (min)	61.0 ms 10.6 ms (jitter)	192.9 ms 10.9 ms (jitter)	35.2 mJ/s	48.5 mJ/s
Flooding (IEEE 802.11)	99.5% 99.4% (min)	88.1% 84.3% (min)	12.3 ms 63.7 ms (jitter)	41.1 ms 69.6ms (jitter)	237.3 mJ/s	240.1 mJ/s

broadcasting. Our goal is to investigate both ends of the delay vs. throughput (quality) trade-off by using NB-TRACE and Flooding with IEEE 802.11. Table 1(a) summarizes the simulation setup we used to investigate these architectures. Acronyms, descriptions and values of the parameters used in the simulations are presented in Table 1(b).

We performed two sets of simulations where each set has a different priority. First, we prioritize the reception of packets with the lowest delay (set I). This leads to faster network-wide broadcasting and mainly the low rate traffic is forwarded by the nodes. In the second set of simulations, throughput is the priority for the nodes (set II), which thus have to forward the high rate traffic. We simulated conversational voice obtained through scalable source coding. The base layer data, which is sent as the low-rate information, is coded at $13Kbps$, and the additional layer, which is sent as the additional-rate information, is also coded at $13Kbps$. This results in a high-rate packet transmission of $26Kbps$.

In Table 2, results of these two sets of simulations are provided. These results show the two extreme ends of the delay-throughput trade-off using multi-rate coding in network-wide broadcasting in MANETs. The low delay constraint results in less traffic and low average throughput for the network, while the average throughput is nearly doubled at the cost of increased traffic and delay when we have throughput as the constraint.

Superposed coding makes different information rates simultaneously available, and this lets nodes decide which set of upstream nodes they need to listen to in order to maximize the overall ratio of data rate/delay and minimize the energy dissipation. We conclude that this multi-rate broadcasting scheme (along with a highly coordinated routing protocol) should prove more efficient in a multicasting scenario where nodes with different throughput requirements and delay constraints can freely chose one of the available rates.

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