A NOVEL APPROACH FOR DATA PIGGYBACKING IN MOBILE AD-HOC NETWORKS

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ABSTRACT

Effective Medium Access Control (MAC) is an important issue for bandwidth efficient Mobile Ad-hoc Networks (MANET) as it coordinates the distributed access to the shared radio channel. Due to the unreliable transmission channels in wireless environments acknowledgement messages are often used to inform the transmitter about the successful reception of a data message. This acknowledgement based handshaking procedure consumes significant parts of the scarce bandwidth resource.

In order to provide higher MANET transmission performance the approach presented in this paper reduces the waste of resources by minimizing the number of channel accesses and required acknowledgements. We propose an approach which achieves this objective by piggybacking the data messages on the acknowledgement in a multi-hopping environment. Instead of a pure acknowledgement the piggybacked data message is transmitted again by the in-between nodes. In a MANET this piggybacked data message implicitly informs the originator about the successful receipt of the message and transmits the data at least one hop further.

In our approach the transmission of pure acknowledgement messages is avoided and the amount of overhead for the acknowledgement is reduced. In addition by piggybacking the data packet on the acknowledgement, the data packet is transmitted one hop further. The data is transmitted at least two hops wide within one channel access cycle. By using additional piggybacked acknowledgements the data packet can be transmitted multiple hops in one channel access cycle.

1. INTRODUCTION

Mobile Ad-hoc Networks (MANET) consist of a number of radios building a temporary network without a centralized infrastructure. The radios communicate directly with their neighbor radios within transmission range and via multi-hopping over in-between nodes for longer distances.

Because of the decentralized structure such networks are robust but need a self-organized control by all network nodes.

Effective Medium Access Control is a key requirement for bandwidth efficient MANET. The broadcast characteristic of the radio resource requires to avoid simultaneous transmissions of more than one radio. Otherwise collisions occur which lead to the loss of the transmitted information. A MAC protocol coordinates the access to the radio resource.

In multi-hop MANETs the existence of hidden and exposed terminal scenarios increase the importance of an efficient MAC scheme.

Due to the unreliable transmission channel in wireless environments acknowledgement messages are often used to inform the transmitter about the successful reception of a data message. This acknowledge based handshaking procedure consumes significant parts of the scarce bandwidth resource.

Common channel access schemes transmit data packets in each transmission cycle one hop wide. Thus at least two channel accesses are needed to transmit a packet out of access range. These additional channel access cycles also consume a significant part of the bandwidth.

Especially in MANETs MAC approaches on the basis of carrier sensing multiple access (CSMA) are quite common. For example the WLAN standard IEEE 802.11 uses CSMA.

To avoid collisions a contention phase is introduced in IEEE 802.11 at the beginning of each access cycle. During that phase the nodes willing to transmit do not transmit immediately but wait a random time period and sense the medium. When the random waiting time is elapsed the node immediately starts transmitting. If another node started transmitting earlier the medium is sensed as busy and the remaining nodes will stand back from transmitting until the next transmission cycle beginning with a contention phase.

From the literature [1][2] approaches are known that use the acknowledgement, which is sent in each access cycle by the receiver to the transmitter, for the transmission of information messages. I.e. a piggybacked data packet out of the receivers queue will be send along with the acknowledgement. These approaches in [1] and [2] differ in the type of the selection of that piggybacked data message.

1. In [1] a data packet destined to the source of the original message is piggybacked.
2. In [2] an arbitrary packet by the receiving node is piggybacked.

The approach described in [1] has the difficulty of finding exactly that message out of the transmit queue, which is destined to the source of the original message. This requires a sophisticated queue handling and is therefore fairly complex.

The approach introduced in [2] sends a message out of the transmit queue of the in-between node to any node with the acknowledgement for the transmitter of the original message. This can lead to a violation of the quality of service constraints, such as throughput and transmission delay, as lower classified messages than the original data packet may be piggybacked. Moreover the second approach decreases the fairness of the channel access as the busy duration of the medium can largely increase with long piggybacked messages.

2. DATA PIGGYBACKING

Common acknowledgement based communication is characterized by transmitting the data packet on the data path and an explicit acknowledgements on the reverse path. Due to the broadcast structure of wireless communications and the bi-directionality of the links all neighbors can hear the data transmission of a node. Thus in a multi-hopping environment a forwarding node has to transmit two packets, the acknowledgement for the received packet and the data packet itself.

Data piggybacking bases on the idea of combining these two pieces of information in one transmission by using the acknowledgement for the immediate transmission of the data packet. The acknowledgement is implicitly included in the data transmission to the next hop.

Figure 1 illustrates this behavior. The data packets are transmitted from the source node via the in-between node to the destination node. On the reverse path the acknowledgement information is provided. This acknowledgement information for the source node is combined with the data packet transmission from the in-between node to the destination (dotted line in Figure 1). Due to the characteristics of the radio channel the transmission from the in-between node to the destination can also be received in the source node. Thus the source node can extract the implicit acknowledgement information (dotted line in Figure 1) from the data transmission of its next hop. An explicit acknowledgement is avoided.

The in-between node must meet the time constraints for the acknowledgement information. Thus the data transmission must start immediately after the receipt of the data packet in the in-between node. The acknowledgment information must not be delayed. In Figure 1 only the in-between node does Piggybacking. Thus the destination uses an explicit acknowledgement to confirm the success of the data transmission from the in-between node to the destination node.

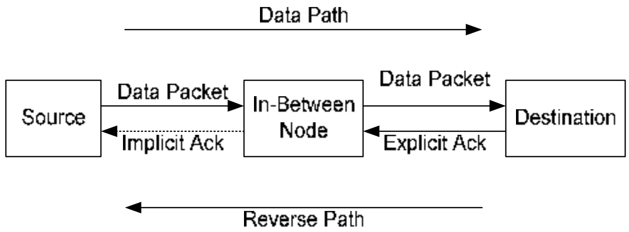

Figure 1: Data transmission and implicit acknowledgement

For CSMA based channel access schemes data piggybacking provides several advantages.

- Only one channel access cycle is needed to transmit the packet multiple hops wide. Thus the delay is decreased by the duration of the additional channel access cycles.
- In a transmission region the number of channel access cycles per packet is decreased. Thus the number of contention phases per packet is decreased and the number of channel access cycles can be minimized. Generally, a node which gets the channel access should transmit the packet out of the current transmission region, i.e. multiple hops wide, to avoid additional channel access cycles for that packet in that region. In that case the number of channel access cycles in a transmission region is reduced.
- Lowering of the number of needed channel access cycles also decreases the probability of collisions as commonly collisions only occur during the channel access cycle. This reduction leads to a lower packet error ratio and avoids time and resource consuming retransmissions.

In our approach the transmission of pure acknowledgement messages is avoided and the amount of overhead for the acknowledgement is reduced. In addition the data packet is transmitted one hop further. The data are transmitted at least two hops wide within one channel access cycle. The piggybacking can also be used on multiple hops. By using piggybacking in several nodes the data packet can be transmitted multiple hops in one channel access cycle.

In order to provide higher MANET transmission performance the approach presented in this paper reduces the waste of resources by minimizing the number of channel accesses and needed acknowledgements.

3. QUALITY OF SERVICE PROVISIONING

Generally, piggybacking of another data packet leads to a quality of service violation if the piggybacked data packet belongs to a different quality class than the original packet. This is caused by the influence of the QoS classification on the random waiting time of the contention phase. Thus the piggybacked data packet would get a better quality of service as planned.

To avoid quality of service violations the transmission of data packets belonging to a different QoS during an access cycle must be avoided. Only the packet, which has won the channel access is allowed to be forwarded and piggybacked during that access cycle. Another data packet with different QoS classification must not be transmitted during that access cycle. The channel access sequence which is caused by the QoS classification must not be changed by the piggybacking.

To meet these requirements our approach uses that packet for the piggybacking which has won the channel access. The win of channel access means that this packet is the most valid at the moment. Due to piggybacking the busy channel duration is increased in an acceptable range. But this does not influence the sequence in which the packets win the access to the channel.

It should be noted that the quality of service provisioning must consider the longer channel access duration caused by the retransmission of our piggybacking approach.

4. DETAILED BEHAVIOR DESCRIPTION

Data piggybacking is provided by the in-between nodes on the data path between the source and the destination within the MANET. It can be realized by one or more in-between nodes. In addition piggybacking and non-piggybacking nodes can also be mixed.

The transmission is initiated by the source node by winning the channel access during the contention phase.

The source node transmits the data packet and expects an acknowledgement as an indication of the correct reception from the next hop node. The acknowledgement is expected after a specific acknowledgement time period. The miss of the acknowledgement indicates a transmission error and leads to a retransmission from the source node.

The next hop node which receives the packet from the source checks the destination address of the packet and finds the next hop node on the path to the destination from its internal forwarding database. Thereafter it directly forwards the received data packet in the direction to the next hop node. The data transmission must start after the specific time period expected by the source node. The source node also receives the data packet from the 1st in-between node to the 2nd in-between node as it must be in the transmission range of the 1st in-between node. The source node recognizes the acknowledgement of its data transmission from the immediate data transmission after the acknowledgement time period from the in-between node or the information included in the data packet itself.

All nodes on the data path except from the destination node can provide the same data piggybacking procedure as the 1st in-between node. The destination node uses an explicit acknowledgement as it has no need to transmit the data packet. Also in-between nodes may use explicit acknowledgements. In that case a separate channel access cycle is needed for the transmission of the data packet one hop further.

Figure 2 illustrates the data piggybacking behavior.

5. FORWARDING

An important aspect for data piggybacking is the compliance with the specific acknowledgement time period of the used channel access scheme. This is needed in order to combine the operation of piggybacking and non-piggybacking nodes within a MANET and to avoid the waste of the scarce radio resource due to an increased waiting duration.

Thus the in-between nodes using data piggybacking must provide the forwarding decision and forwarding for the incoming packet without violation of the acknowledgement time period. Otherwise the source node would not detect the implicit acknowledgement within the data packet.

To meet these timing constraints the channel access and the forwarding must closely co-operate. On the receipt of a packet the node must check the destination address included in the data packet and decide if it must forward the packet. If it has to forward the packet it must find the next hop node on the forwarding path to the destination. Thereafter the node transmits the packet and implicitly acknowledges the former transmission.

The behavior within the in-between node depends on the forwarding approach in use.

In the case of *data link layer forwarding* (switching) after the forwarding decision the node only has to retransmit the received data packet. As the data link header is unchanged the former transmit node can generate the acknowledgement information from the fact, that the same packet has been transmitted from the next node. This can for example, be done by interpreting the time stamp of transmission by the next node, which indicates the acknowledgement, or by saving the appropriate information from the packet (e.g. source address, destination address, sequence number).

In case of the more common *network layer forwarding* (routing) data piggybacking requires a more complex operation. This is caused by the fact that the destination address of the end-to-end data path is included in the network layer header. The data link layer header only includes the addresses for the one hop wide transmission. This means, that the node must provide the forwarding decision on basis of the destination of the network layer header. This information must be extracted from the network header of the packet. After the decision the node must build a new data link layer packet, which includes the network layer packet as its payload. The new generated data link header includes the acknowledgement information (e.g. sequence number) for the former transmit node (e.g. source node).

To provide the fast forwarding which meets the timing constraints of the channel access the data link layer must be closely interconnected with the network layer forwarding database. This can be reached by a cross layer approach, which combines the regarding tasks of the data link and network layer. An important aspect in that context is the fast access from the data link layer to the forwarding data base.

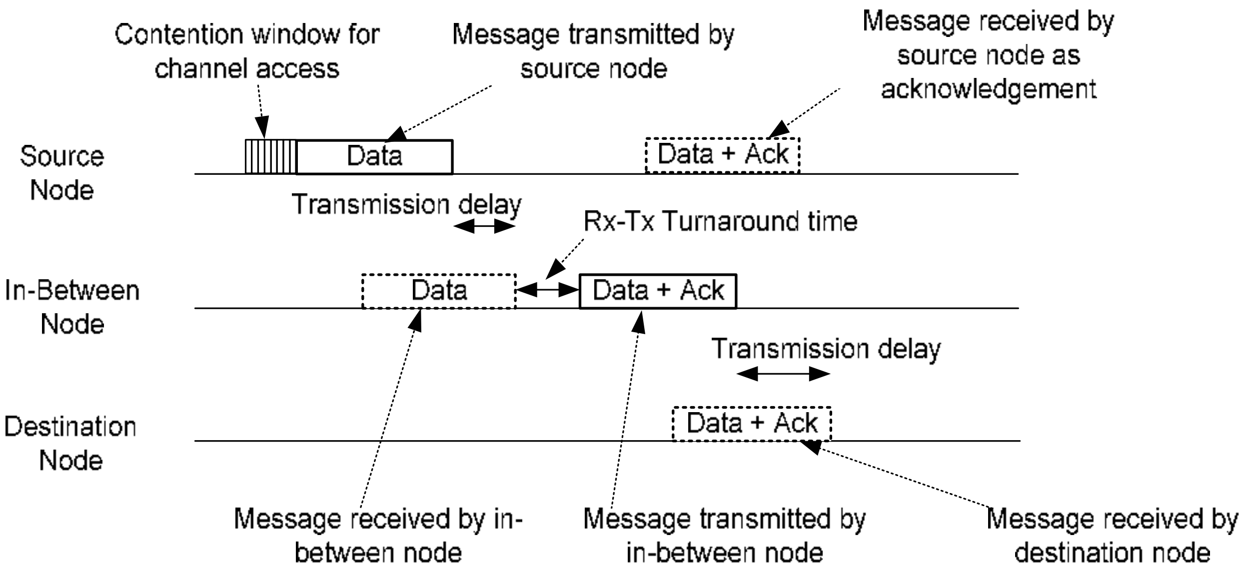

Figure 2: Exemplary transmission sequence

6. EVALUATION

For the evaluation of our approach we used a simulation environment similar to IEEE 802.11 [3]. The simulated application traffic is digitized voice traffic on basis of the ITU G.729a standard [4]. During our evaluation we used the common IEEE 802.11 MAC scheme [5] as a reference.

Figure 3 illustrates the simulation results for the number of simultaneous voice calls over the number of needed hops between source and destination. It can be seen that the number of simultaneous voice calls, effectively the throughput, decreases with increasing number of hops between source and destination. This is caused by the fact that the number of transmission attempts increases with the number of hops. In addition the results show the performance increase of data piggybacking with respect to the common approach if the transmission uses multiple hops. In the case of only one hop wide transmission data piggybacking provides no benefit as no retransmission is needed. So the throughput is the same as with the common 802.11 MAC scheme. In the case of a two hop wide transmission the performance is significantly increased with data piggybacking. The number of simultaneous voice calls is increased by 50% with respect to the common 802.11 MAC scheme. If the number of hops between source and destination is increased further the data piggybacking also increases the number of simultaneous voice calls. Due to a lessened coordination of the hops on the transmission path the performance increase is not as high as with the two hop wide transmission. Nevertheless the common 802.11 MAC scheme is still outperformed.

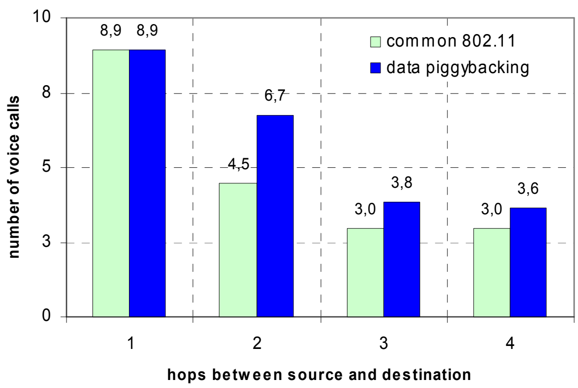

Figure 3: Number of Voice Calls over hop count

Figure 4 shows the delay results of our evaluation. It can be seen that the delay increases with the number of hops on the transmission path. This result was to be expected as more hops are needed. Except from the one hop wide transmission the transmission delay is lower with our data piggybacking approach. This is caused by the avoidance of additional channel access cycles by the multi hop transmission. Thus the difference of delay between our novel data piggybacking approach and the common 802.11 MAC scheme increases with the number of hops between source and destination.

The reduced transmission delay leads to a better quality of service of the data transmission especially for interactive applications.

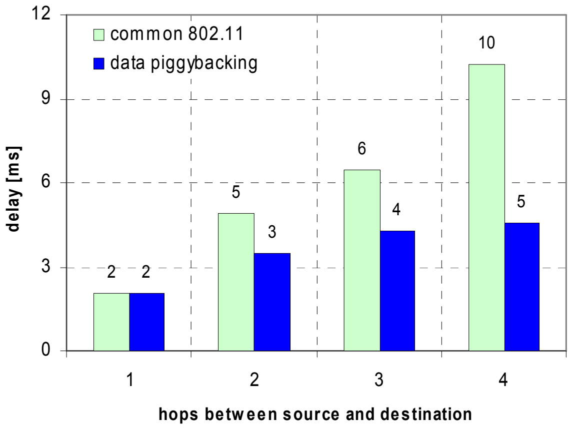

Figure 4: Delay over hop count

Figure 5 illustrates the simulated packet loss ratio for a MANET with 25 active nodes. It can be seen that by using the data piggybacking approach the loss ratio can be reduced. The reduction is caused by the decrease of collisions during the contention phase. The reduced packet loss ratio also increases the quality of service especially for real time applications like voice or video, which commonly use the unacknowledged transmission protocol UDP.

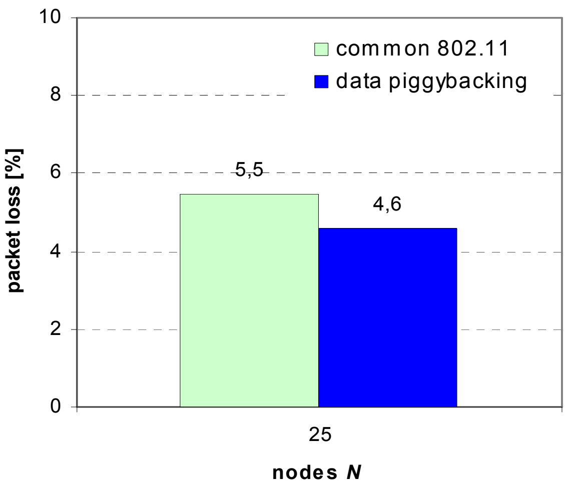

Figure 5: Packet loss ratio

7. CONCLUSIONS

In this paper we present a novel approach for data piggybacking in MANETs. Except from the common one hop wide transmission a data packet is transmitted multiple hops wide in each transmission cycle. The multi-hopping reduces the number of needed channel access cycles which leads to a significant performance increase with respect the common 802.11 access scheme which was used as a reference during evaluation.

The results presented in this paper show a significant performance increase by data piggybacking of up to 50% throughput. In addition the delay is decreased which improves quality of service for real time applications, such as voice and video. Due to the decreased number of required channel accesses per packet transmission the packet loss ratio and collision probability decrease too. The increased transmission reliability leads to a higher service quality. This avoids retransmissions resulting in a higher packet delivery probability. In contrast to existing piggybacking schemes our approach maintains the quality of service constraints of the data messages as only the data packet is transmitted which has won the channel access during the regular contention phase. Thus quality of service violations caused by the piggybacking of lower classified data packets are avoided. In addition, data piggybacking is easy to implement. The proposed approach increases the efficiency of multi hop transmission and leads to a higher transmission performance of the MANET. The scarce radio resource is used in an efficient way and the mobile capacity of the whole MANET is increased.

Although in this paper the simulations occurred with a CSMA-based scheme our approach also suits to other channel access scheme, such as time division multiple access (TDMA).

8. REFERENCES

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