Performance Analysis of Prediction Based Routing Algorithms

Erik Weiss*, Bangnan Xu+, Sven Hischke++
* : Communication Networks, Aachen University, RWTH, Kopernikusstr.16, D-52074 Aachen, Germany
+: T-Systems, Technologiezentrum, Am Kavalleriesand 3, D-64295 Darmstadt, Germany
++: Deutsche Telekom AG, Friedrich-Ebert-Allee 140, D-53113 Bonn, Germany

Ph: +49 241 8028575, Fax: +49 241 8022242, Email: erik.weiss@comnets.rwth-aachen.de

Keywords: ERRA, ERU, Link Prediction, IEEE 802.11, IPonAir

Abstract

This paper presents a new concept to improve ad hoc routing protocols that exploit the IEEE 802.11a link adaptation information. The IEEE 802.11a Link adaptation information is used to predict the link stability and link lifetime. After introducing the IEEE 802.11a MAC layer information and its transmission modes, the paper reviews some insights of the IEEE 802.11a link adaptation behaviour. Based on the link layer information, new route maintenance Protocols ERRA (Early Route ReArrangement) and ERU (Early Route Update) are proposed to improve the active route maintenance in ad hoc networks. This paper describes a basic link adaptation algorithm and presents the performance gain of the two approaches.

1 INTRODUCING

While it is increasingly important to be connected to the internet world, the trend goes towards wireless solutions, providing public access to the Internet at high data rates. *Wireless Local Area Networks* (WLAN) like IEEE 802.11a work at the 5 GHz and support transmission rates up to 54 Mbit/s. The high attenuation at 5 GHz limits coverage. One objective is therefore to extend the coverage by establishing multi-hop routes. Since being wireless enables the user to be mobile, the network has to deal with all the effects introduced by a dynamically changing network topology.

High throughput and limited transmission range makes WLAN systems adequate for areas with a high population density and users with the need for high data rates. Such places, like airports or fairgrounds, are called Hotspots. Covering large areas with WLAN is economically inefficient, since a considerable number of Access Points (AP) and routers would have to be installed due to the limited transmission range.The AP density could be reduced by either increasing the transmit power or enabling intermediate terminals to forward the data to users outside the Access Point range. High transmit powers strain the batteries of the mobile devices and increase the exposure of operators to radio waves, along with their yet undetermined health risk.

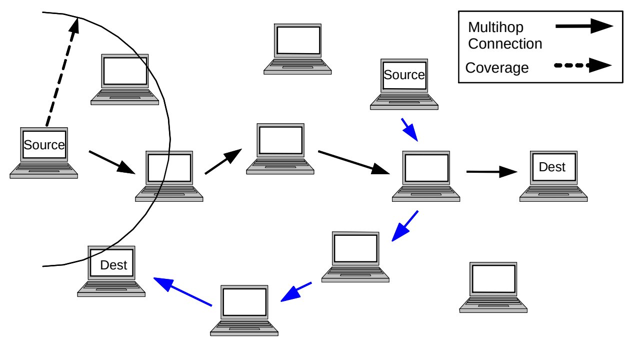

Figure 1: Wireless Ad Hoc Network

State of the Art

Today's solution is to expand the fixed infrastructure using multi-hop connections. Mobility and fast changing topologies are addressed by ad hoc routing protocols, which can be divided into proactive and reactive protocols. Reactive protocols request a route when needed, whereas proactive protocols permanently maintain routes to all network members that can be used on request, therefore minimizing packet delay. Reactive protocols avoid maintaining unneeded routes at the cost of a higher route discovery and packet delay. Furthermore, hybrid approaches have been developed. However, when a route breaks, all routing approaches try to recover the connection. Most routing algorithms inform the source node that then starts a completely new discovery process, thereby flooding the network with a large number of signalling messages. Some routing protocols try to keep the route discovery locally around the breakage, hence the flooding is limited. Moreover, all aforementioned approaches only react properly when the link is already broken, which leads to a high number of lost packets as well as increased route rediscovering and packet delay.

The new strategy proposed in this paper does not wait until the link breaks. Based on link adaptation information we predict the link state and start to rearrange the route before the link is interrupted. Lower layer, especial the link adaptation provides information that allows predicting the link conditions. We present two new route rearrangement protocols based on prediction, Early Route Rearrangement (ERRA) and Early Route Update (ERU).

Since the presented approaches prevent unnecessary signalling, avoid packet loss and minimize packet delays, our approach uses the ad hoc network capacity more efficiently than existing protocols.

The remaining parts of the paper are organized as follows: we start with a brief survey of IEEE 802.11. The link adaptation fundamentals are covered in section 3, followed by a discussion on how the link adaptation supports the necessary prediction information in the fourth section. After giving a brief description of the ERRA and ERU signalling procedures, we highlight the benefits of the new protocols. The last section concludes our consideration.

2 IEEE 802.11a MEDIUM ACCESS CONTROL

The IEEE 802.11a Medium Access Control (MAC) layer is mainly the same as the MAC layer of 802.11b and the legacy 802.11. The main difference to 802.11a are the transmission modes [1][2]. 802.11a offers no less than eight coding schemes, so called ”*PhyModes*” (cf. Table 1) IEEE 802.11 uses a distributed MAC protocol, the *Distributed Coordination Function* (DCF). The 802.11 standard also defines a *Point Coordination Function* (PCF) but no vendor has implemented it. The DCF is based on *carrier sense multiple access with collision avoidance* (CSMA/CA). For mobile nodes (MN) it is not possible to monitor the air interface while transmitting. Hence, the DCF uses backoff and request-/ clear to send (RTS/CTS) mechanisms to avoid collisions. Details of the IEEE 802.11a MAC protocol are given in [2].

IEEE 802.11a Transmission Modes

The IEEE 802.11a standard does not specify rules for selecting the transmission mode. The first four bits within a packet preamble refer to the PhyMode used for coding the data. Higher transmission modes are capable to deliver higher data rates, but need a considerably higher carrier-to-interference ratio (C/I), thus limiting the bridged distance (cf. Figure 2). In Table 1 the available modes are listed together with the maximum data rate and bits per OFDM symbol [2][1]. Due to the dependency between C/I and useable transmission mode, IEEE 802.11a allows to change the transmission mode when the channel quality is decreasing, e.g. due to a rising distance between source and destination. The IEEE 802.11a system offers the possibility to choose an individual PhyMode for every connection and every data packet. The idea is to choose always the PhyMode with the best balance of throughput and packet error rate (PER). Since terminals in a real system can not determine between signal power and interference power, it is impossible to

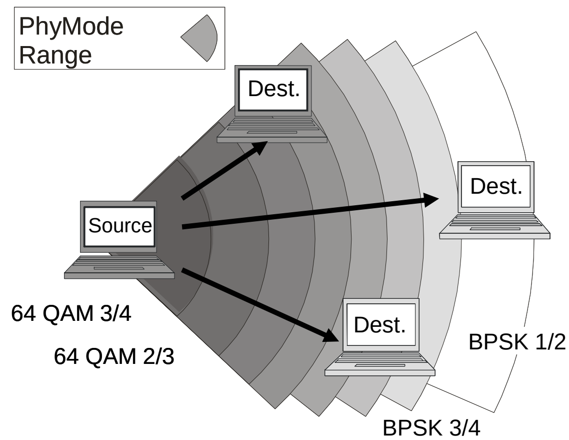

Figure 2: PhyMode Range

measure the C/I, each terminal only receives a certain ’Energy’[i]. Two ways exist to estimate the signal-to-noise ratio: Terminals could either measure the interference power within transmission breaks, or the successfully received and the lost packets are counted.

The ratio between received and lost packets, combined with the known packet error rate (PER) per PhyMode, leads to the current C/I. At the Chair of Communication Networks, a IEEE 802.11/a/g/e network simulator has been developed that is based on PER measurement versus the carrier-to-interference ratio. The implemented link adaptation based exclusively on successful/lost packets.

Data rate (Mbit/s)	Modulation	Coding rate (R)	Data Bits per Symbol
6	BPSK	½	24
9	BPSK	¾	36
12	QPSK	½	48
18	QPSK	¾	72
24	16-QAM	½	96
36	16-QAM	¾	144
48	64-QAM	2/3	192
54	64-QAM	¾	216

Table 1: Mode Dependent Parameters

3 IEEE 802.11a LINK ADAPTATION BEHAVIOUR (LA)

Since IEEE 802.11 does not define any rules for an internal link adaptation (LA), each vendor implements a proprietary LA. Independently from the flavour of the LA, all algorithms are based on the similar principle, that is, with degrading channel conditions a lower but stronger PhyMode is chosen (or a higher but weaker one, when the conditions im

[i] This is the reason why routing protocols based on signal strength stability operate on an uncertain basis. The received signal strength changes very dynamical due to the burstiness of the traffic.

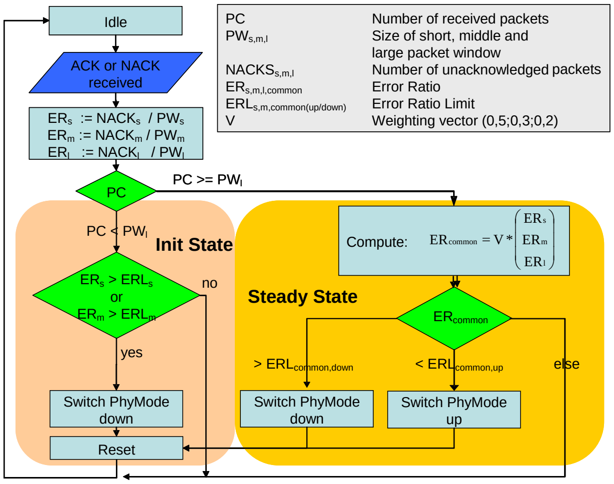

Figure 3: Link Adaptation Working Principle

prove). To evaluate the performance of the IEEE 802.11a MAC, our simulation tool has been extended with a fast and efficient LA. The developed LA could e seen as an enhanced version of the Auto Rate Fallback (ARF) [8] protocol; the implemented version addresses the following design principles:

Fast reaction on condition changes is one of the major requirements for an LA, while slow changes must be considered as well. To fulfil these requirements, our LA contains three different buffers of size 5, 10 and 25 to store the PhyModes used in the past, along with the information whether the packet has been acknowledged or not. When the error ratio associated to a buffer is exceeded, the PhyMode is decreased immediately. The LA starts in an initial state until all buffers are filled. In this state, the LA converges fast from the initial PhyMode to the current link conditions. It is particularly important to reach an applicable PhyMode before the IEEE 802.11 protocol starts discarding packets.

Therefore, a medium coding scheme is chosen for the initial PhyMode. Once all buffers are filled, the LA switches to the steady state where all buffers are considered, weighting the short packets higher than the longer ones. The LA uses a weighting vector to combine the different error rates. The resulting error ratio is used to decide whether the PhyModes has to be increased, decreased or left unchanged. When the link to a certain neighbour is idle for a given period of time, all buffers of the according LA instance are deleted to avoid stale information. Consequently, whenever a node wants to communicate with another node and it is either the first time or the link has been idle for a certain time the initial PhyMode must be used at the beginning.

Using the initial PhyMode could be avoided if a connection existed in the opposite direction. Figure 5

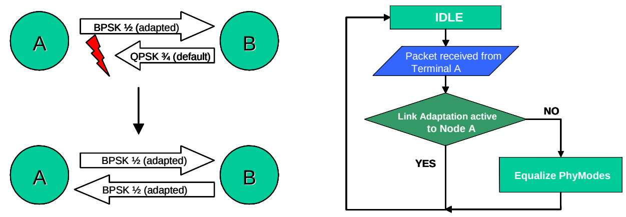

Figure 4: Considering the Bidirectional Case

illustrates this strategy: Node A transmits using BPSK ½ to node B, which means node A has adapted the PhyModes until an adequate one was found. Hence, node B uses this coding scheme as the initial PhyMode. The proposed LA is built to work in an ad hoc network. One LA instance only serves one destination. Figure 5 presents two typical LA reactions: A pure ad hoc scenario has been investigated containing 40 nodes all moving according the Random Waypoint Model (RWP) [6]. Three routes have been simulated. Each source produces 100 kbit/s constant-bit-rate traffic with 512 byte per packet.

Figure 5 shows the adapted PhyModes from one of the source nodes: Due to the mobility the next hops are changing. On the left hand side, terminal 29 was the next hop, on the right hand side it was terminal 12. The typical behaviour ("downstair-pattern") prior to a link break (thick dashed line) can be observed.

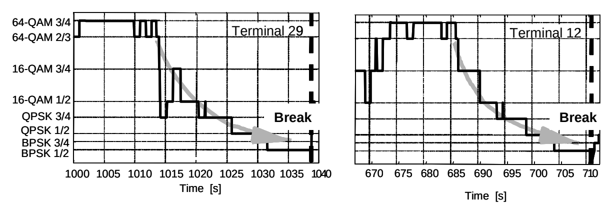

Figure 5: Example for the Link adaptation behaviour

4 PREDICTION BASED ON THE LINK ADAPTATION

The two subplots in Figure 5 illustrate that the link quality degrades when the node departs from its communication partner. The LA adapts whenever necessary the PhyMode to avoid interrupting the connection. Due to this behaviour we are able to predict the link interruption. Continuous degradation of the PhyMode is a hint for the network layer that the link may break soon. This information triggers the routing to change and to adapt the route according to the actual situation. Being able to predict a link interruption has large benefits. The usual routing protocols only react after the link is broken, while, when exploiting LA information, they can act before the breakage occurs.

The next step is to evaluate the relation between this "downstair-pattern" and a route interruption. Therefore we

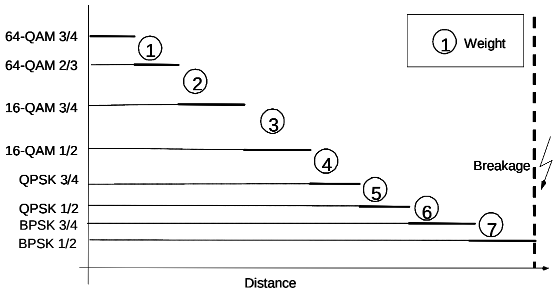

Figure 6: Weighting Steps

define a weighting vector that weights the importance of each PhyMode step related to the breakage (cf. Figure 6). Changing from BPSK ¾ to BPSK ½ (weight 7) is more important for the breakage prediction as switching from 64 QAM 2/3 to 16 QAM ¾ (weight 2). When the LA has to use the strongest PhyMode (BPSK ½), it checks the steps in the past for the "downstair-pattern". The LA adds up all switching steps for a certain time interval, when the sum exceeds a limit. The link is considered suspicious and might break. This information triggers the routing layer to update the route. A detail prediction description can be found in [5].

5 ERRA: EARLY ROUTE REARRANGEMENT

In the previous section we presented how to forecast the degradation of a link. This section describes an approach that profits from early triggering. The Early Route ReArrangement (ERRA) is derived from the local repair idea, which is part of the Ad Hoc On Demand Distance Vector (AODV) routing [3] protocol.

ERRA does not wait until the link is broken; prior to a breakage, ERRA rearranges the route to avoid disruption. In Figure 7 a signalling example is given. The initial route starts from source node 2 to destination node 7. One intermediate node (5) is going to leave the connection. This can be detected by node 4; it has to adapt the PhyMode to node 5. Accordingly, node 4 triggers the ERRA procedure to rearrange the route, when the PhyMode BPSK ½ must be used.

Node 4 locally broadcasts[ii] a rearrangement request (ERR_REQ) with a predetermined PhyMode that is higher than the last one used for the connection. In Figure 7 the request is sent with QPSK ½, thus node 5 does not receive the request directly. Node 8 forwards the request to node 6 which is aware of a route to the destination.

[ii] The time to life (TTL) for the broadcast is calculated according the AODV local repair rules [3]

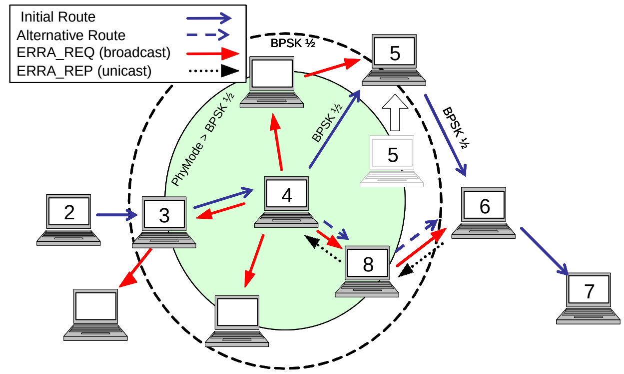

Figure 7: ERRA Signalling

Node 6 responses (ERRA_REP) and provides an alternative route. Node 4 compares the hop count between old and new route. If the new hop count is smaller or equal, the route is used immediately. Otherwise node 4 uses the new route as soon as the old connection is broken. Further details can be found in [5].

ERRA is going to rearrange the route to provide uninterruptible connections, since route continuity is a important requirement for transport protocols. However, ERRA is wasting one feature in the presented situation.. In the moment a notification for a degrading route is received, the connection still exists and can be used for the route update process. Therefore we have extended ERRA and developed the Early Route Update protocol.

6 ERU: EARLY ROUTE UPDATE

Instead of waiting until a connection breaks, ERU acts in advance. The node before the suspicious link deals with the node behind the upcoming breakage to find a workaround. We utilize the fact that each node monitors its entire incoming and outgoing links. Furthermore we assume that each node has an up to date list of its neighbourhood.

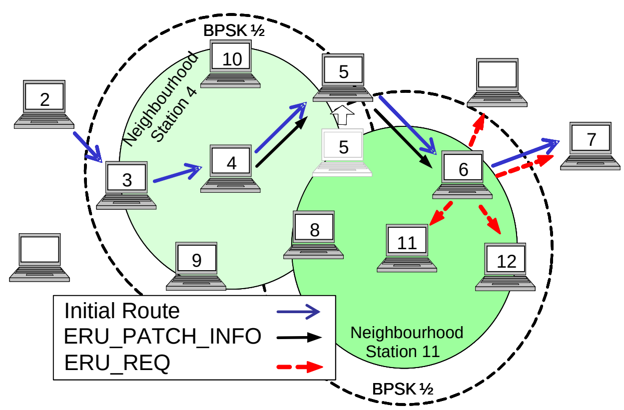

Figure 8: ERU Request Signalling

Figure 8 illustrates the ERU signalling: Again, node 5 leaves the route. Node 4 gets trigged by its LA about the suspicious link and adds a list of its neighbourhood to an ordinary data packet[iii] (ERU_PATCH_INFO) that is received by node 5.

Since node 5 is informed by its LA that its incoming and outgoing connection for that particular route are suspicious, it is going to leave the connection, forwarding the information to the next hop. Node 6 has a stable outgoing link therefore it separates the list of neighbours form the data packet. First it compares the list with its own neighbourhood. In Figure 8 there is no intersection between the set of neighbours. Hence node 6 broadcast the list. The number of broadcasts are derived from the number the ERU_PATCH_INFO has been sent (in our example the info is sent twice). Thus the broadcast is limited to the vicinity of the disruption. In Figure 9 it can be seen that node 11 knows about node 8, which is also included in the neighbour list.

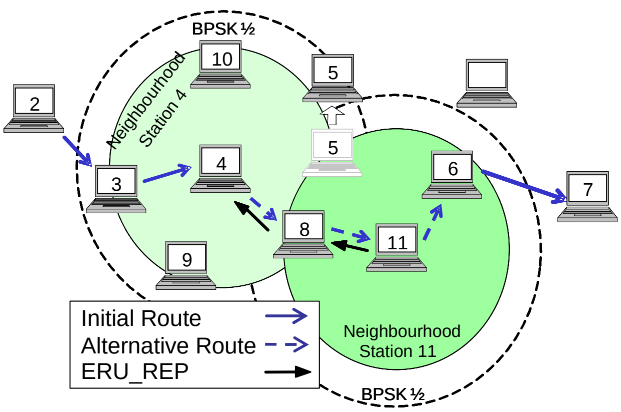

Figure 9: ERU Reply Signalling

Therefore node 11 creates a reply message (ERU_REP) and sends this to node 4 via node 8. Node 4 applies the same rules for using the new connection as already mentioned for ERRA. Some special cases must be considered, e.g. the situation when source or destination are within the neighbourhood. A detailed treatment can be found in [5].

7 Simulation Results

We simulated several scenarios, investigating the LA and the cross-layer interaction between LA and IP routing. The scenario consists of a square area (100m x 100m) with 40 nodes moving according the RWP [6] mobility model. Three routes are loaded with constant-bit-rate traffic; the amount of traffic is increased per simulation. The packet size is 512 bytes, RTS/CTS is use to avoid the hidden node problem.

Figure 10 presents on the left hand side the average throughput percentage over all three routes, the ERRA and ERU approach are compared with the AODV local repair mechanism. It can be seen that under high load conditions the network gets congested and can not provide a sufficient throughput. More important, no throughput degradation can be seen with the ERRA or ERU strategies. It must be mentioned that both approaches affect only a small fraction of packets. On the right hand side the average Hop Counts versus offered traffic is shown. Under low traffic conditions ERRA and ERU

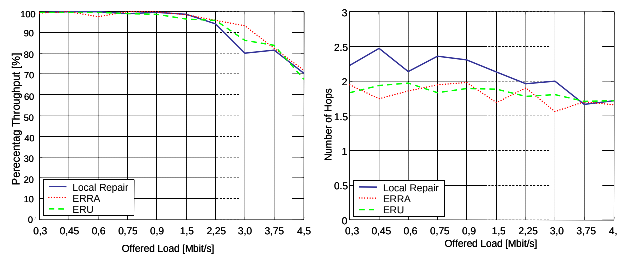

Figure 10: Throughput Percentage and Average Hop Count

shorten the route. When the offered traffic increases, ERRA and ERU reveal the same performance as local repair. They do not negatively influence the throughput, but shorten the routes. More important than throughput or hop count is the packet delay. By avoiding route breaks the packet delay is decreased.

Figure 11 shows four complementary cumulative distribution functions (CDF), each representing the delay distribution under different traffic conditions. It can be seen that both approaches outperform the local repair.

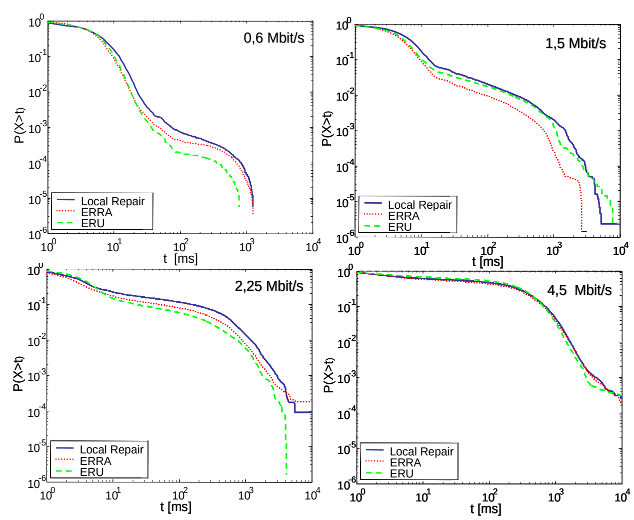

Figure 11: Delay under different load situations

[iii] Assuming the IEEE 802.11 maximum packet (2304Byte) size is not exceeded

Under low load conditions ERU shows the lowest delay. With an increasing amount of traffic both still show smaller delay than local repair. This is a proof, in our opinion, that link prediction improves the route continuity, avoids packet losses, and decreases packet delay because a new route discovery is avoided.

8 Discussion

This paper presents the Early Route ReArrangement and the Early Route Update approach. Both are based upon the breakage prediction. The shown results are promising and further studies will show how much ad hoc routing can benefit from lower layer information and form predicting based upon such knowledge.

Several aspects must be further investigated and enhanced during the next steps. The presented LA can evidently not distinguish between packet loss originated by transmission errors or collisions. In a congested channel, the LA only knows there are unacknowledged packets. The reaction is, obviously, decreasing the PhyMode. This however increases the packet sizes and worsens the situation. In the described case the behaviour is suboptimal and will be enhanced in the future by monitoring the MAC queue length. When the channel busy time increases, congestion is more probable. This could be observed by monitoring the MAC transmission queues. Therefore the queue length should influence the LA decisions.

While the current LA will not increase the PhyMode in case the channel is congested. An enhanced LA might just decide to do so. By increasing the PhyMode the congestion is resolved and links that can not be supported anymore with the increased PhyMode have to find routes around the local congestion. Also, more realistic traffic has to be investigated. The real focus of ERRA and ERU is to improve the performance of TCP by avoiding packet losses through route interruptions.

9 Conclusion

This paper gives a glimpse to the potential of cross layer interaction. We presented the idea to predict the link state based upon the link adaptation behaviour. The prediction trigger can be used by either ERRA or ERU to adapt the route. These early reaction avoids route interruption and provides an alternative route avoiding the suspicious link. By means of simulation results the effectiveness of the approaches has been proven. The next steps are: refining the link adaptation and extending the simulations, by using more realistic and sophisticated services like HTTP or FTP. We will present further results in the next publications.

10 Acknowledgement

This work was supported by T-Systems, Deutsche Telekom and the German research project IPonAir, funded by the German Ministry for Education and research (BMBF). The authors would like to thank the members of the project for the valuable discussion.

References

[1] B. Walke, *Mobile Radio Networks*. New York, USA: Wiley & Sons Ltd., 1. ed., 1999.

[2] IEEE LAN/WAN Standards Committee, "*Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in 5 Ghz Band*" IEEE Std 802.11a-1999, IEEE, New York, Nov. 1999.

[3] C. Perkins, E. Belding-Royer, S. Das. *Ad Hoc On-Demand Distance Vector (AODV) Routing*. RFC 3561, IETF Network Working Group, July 2003. Category: Experimental.

[4] C. E. Perkins. *Ad Hoc Networks*, USA, Addison-Wesley, December 2000.

[5] E. Weiss, M. Frewel, B. Xu. *Improving Ad Hoc Routing for Future Wireless Multihop Networks*. Proceeding of European Wireless 2004, Barcelona, Spain. February 2003.

[6] Bettstetter C., Hartenstein H., Pérez-Costa X. *Stochastic Properties of the Random Waypoint Mobility Model.* ACM/Kluwer Wireless Network, Special Issue on Modelling & Analysis of Mobile Networks, März 2003.

[7] E. Weiss, G. Hiertz, S. Hischke, B. Xu, *Performance Analysis of AODV on Top of IEEE 802.11a and the Impact of the 5GHz Channel*. In Proceedings of Wireless 2003, Calgary, Canada, July 2003.

[8] A. Kamerman and L. Moneban. WaveLAN II: *A high-performance wireless LAN for the unlicensed band.* Bell Labs Technical Journal, pages 118-133, Summer 1997

Biographies

ERIK WEISS received his diploma degree in Electrical Engineering in 2001 from Aachen University, RWTH, Germany. After his studies he joined the Chair of Communication Networks, Prof. Dr.-Ing. B. Walke, at Aachen University, where he is working towards his PhD degree. He participates in the IPonAir project in cooperation with T-Systems. His working areas are integrating heterogeneous systems, IP mobility, Cross-Layer Communication, and Routing in Ad Hoc Network. His current research interests are development of a common inter-system architecture, performance analysis of vertical handover mechanisms between GSM/GPRS/UMTS and IEEE 802.11a/g/b.

BANGNAN XU received his B.Sc. and M.Sc. degrees in electrical engineering from Dalian Maritime University, Dalian, China in 1986 and 1989, and PhD (Dr.-Ing.) degree in information technology from Aachen university of Technology in 2002, respectively. From 1996 to 2001, he was a research assistant at the chair of communication networks, Prof. Dr.-Ing. B. Walke, Aachen University of Technology. Since 2001, he has been with T-Systems, Deutsche Telekom, working as F&E Expert and Projektmanager in the department of Mobile & Wireless Solutions.

SVEN HISCHKE received the diploma degree in Electrical Engineering from the University of Applied Sciences Giessen-Friedberg and the PhD degree from City University London in 1996 and 1999, respectively. From 1999 to 2003 he was with T-Systems in Darmstadt where he was responsible for different research projects in the area of broadband wireless systems and mobile networks focusing on the design of IP-based architectures. Currently he is a program manager for R&D projects within the corporate innovation department of Deutsche Telekom.