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Published in:
7th IEEE Consumer Communications and Networking Conference (CCNC), 2010

DOI (link to publication from Publisher):
10.1109/CCNC.2010.5421825

Publication date:
2010

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Nielsen, J. J., Madsen, T. K., & Schwefel, H-P. (2010). Mobility Impact on Centralized Selection of Mobile Relays. In *7th IEEE Consumer Communications and Networking Conference (CCNC), 2010* (pp. 148-152). IEEE Press. https://doi.org/10.1109/CCNC.2010.5421825

Mobility Impact on Centralized Selection of Mobile Relays

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***Abstract*—This paper considers the impact of node mobility on the selection of the lowest bit error rate (BER) relay path from access point to destination node in a downlink data transmission scenario. The access point uses link signal to noise ratio (SNR) measurements provided by the mobile nodes to select the path either as direct or two-hop via a mobile relay. The impact of delays in the measurement collection procedure in this scheme is analyzed in comparison to an ideal selection and an always direct scheme. An ns-2 and matlab based simulation framework is used to investigate effects of varying scenario parameters on the achieved average BER of data transmissions. The SNR measurement collection is based on periodic hello broadcasts.**

Results show that increasing node speed can lead to performance that is worse than always transmitting directly. The hello broadcast rate can mitigate this effect, however, at the cost of an increase in signaling overhead. We find that discarding old measurements can significantly improve the BER performance without increasing the signaling overhead. This result establishes the importance of joint tuning of the hello broadcast rate and the measurement storage time.

I. INTRODUCTION

In wireless networks, the performance of data transmissions is depending on the distance between transmitter and receiver nodes as well as on the number of collocated nodes and their activity patterns. Neighbor nodes can cause performance degradation due to interference and collision. Furthermore, when there is a large distance between the transmitter and receiver, rate adaptation schemes switch to a more robust modulation scheme, which decreases the transmission rate. As shown in [1] this reduction in transmission rate can significantly reduce the network capacity, and thereby also transmissions with high rate may be affected. By introducing relaying techniques, nodes located between a transmitter and receiver pair can be exploited to provide a multihop path with shorter links. The shorter links between nodes may form a more reliable path to the destination node, which allows to achieve a higher throughput, see references [2][3][4].

Existing work, such as the coopMAC protocol [1] is targeted at stationary wireless networks. As shown in [1], mobility outdates information about potential helper nodes, which causes performance to decrease to the same level as if relaying was not considered. Even with low mobility (max 1 m/s, 60 s pauses), the gain compared to standard 802.11 is less than 10%. The Harbinger protocol described in [5] copes better with mobility. The protocol assumes that nodes are aware of their position, e.g. by being equipped with GPS receivers and that the position of the destination is contained in the packet header. By letting the contention time depend on a receiving node's distance to the destination, the receiving node closest to the destination will act as the relay and the packet is forwarded towards the destination. However, since the relay nodes are chosen on a per-hop basis, the chosen path is not necessarily the best path. A slightly different approach is taken with the CCMAC protocol [6], which aims at improving throughput for uplink transmissions in the region near the access point (AP) by allowing simultaneous source to relay transmissions.

In this work we consider the scenario where mobile users primarily need to make downlink transmissions. Audio or video streaming are examples of applications leading to such traffic patterns. In such downlink scenarios we will therefore focus on *centralized two-hop relay selection* where transmissions from the AP may be direct or via a two-hop relay path. As in the coopMAC protocol, we rely on maintaining an up-to-date view on the potential relay nodes, but for the downlink case, only the AP needs to have an updated view.

The AP's ability to determine the best path depends on the accuracy of the AP's view on the links properties in the network. The age and availability of link measurements in relation to the movement speed of the mobile devices (MDs) is expected to impact the accuracy of the choice of path. In addition to these factors, also the number of nodes is expected to influence the path selection. In this paper we will investigate how the path selection is impacted by these factors.

In section II we outline the considered scenario and describe the path selection problem in details. Section III describes the method used for evaluation and introduces the considered performance metrics. The evaluation results are presented and discussed in section IV, before the paper conclusion and outlook is given in section V.

II. SCENARIO

We consider downlink transmissions from a fixed AP to MDs in an IEEE 802.11 network. Data transmissions can be done directly to the destination MD or as a two-hop transmission via any intermediate relay node, as sketched in

This work has been performed in the framework of the ICT project ICT-217033 WHERE, which is partly funded by the Framework Program 7 of the European Commission.

The Telecommunications Research Center Vienna (ftw.) is supported by the Austrian Government and by the City of Vienna within the competence center program COMET.

Fig. 1. A relayed transmission is only considered if it provides a better transmission quality than a direct transmission. In this work the goodness of a transmission is determined in terms of the achieved BER. That is, the relayed transmission is chosen if the condition in (1):

$$BER_{\text{two-hop}} < BER_{\text{direct}} \tag{1}$$

In order for the AP to make this decision it needs to estimate the BER of the network links. The BER is estimated from the measurements of link SNR, which are obtained from MDs and collected by the AP. We assume in the following that this mechanism is realized as a L2 protocol extension.

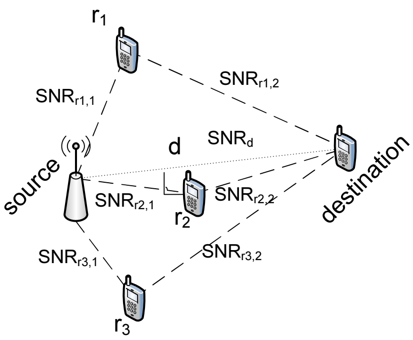

Fig. 1. Example of possible direct and two-hop paths.

By letting all MDs broadcast *hello* messages periodically with average interval duration $\mu_{\text{hello}}[\text{s}]$, other devices within receiving range are able to measure the received signal strength (RSS) and thereby the SNR of the hello broadcast. This measurement is assumed to represent the link state at this moment in time. Further, all nodes are using the same fixed transmission power. The hello message is a IEEE 802.11 MAC frame without payload (20 octets), since only the MAC address is needed for the receiver to identify the broadcast source. Notice that hello broadcasts may be lost if collisions occur.

Whenever an MD overhears a hello broadcast and thereby obtains an SNR measurement, it assembles a measurement frame and sends it to the AP using a unicast transmission. Due to the small frame size, RTS/CTS is not applied but standard 802.11 retransmissions are used if needed. The measurement frame is envisioned as being a MAC control frame that carries the MAC address of the hello broadcast source (6 octets) and the SNR measurement (2 octets), which amounts to a frame size of 28 octets when adding this information to the standard 802.11 control frame layout [7]. Hereby N hello broadcasts lead to $N \cdot (N-1)$ measurement transmissions to the AP, in the case where all nodes receive all hello-broadcasts. The actual amount of measurement transmissions may vary due to losses and possible retransmissions. As this approach generates many individual transmissions that contribute to the overhead it could be considered to accumulate a bulk of measurements before initiating a transmission to the AP. However, as this introduces additional delay, we will not consider this further.

The AP identifies the link from which the measurement has been obtained from the MAC addresses of the broadcast node and measurement node. The AP stores only the most recent measurement obtained for a link. Further, it is assumed that links are symmetric. Since old measurements may be misleading due to mobility of the MDs, it is assumed that the AP discards measurements when their *storage time* exceeds α_{store}. We can further define the age of a measurement as the elapsed time since the hello broadcast of the latest measurement for that link was initiated. The age of a link measurement is a stochastic process that is influenced mainly by the hello broadcast generating process. The inter-event time for hello broadcasts is added a random jitter, which ensures that hello transmissions from different MDs are not in sync. Further, since the MDs' movements are independent of each other, the mobility model is assumed to be ergodic.

Having obtained SNR measurements from links between devices in the network, the AP now chooses the best path according to eq. (1). The BER is estimated from the SNR given the considered path loss and fading models (see Table I) using theoretical expressions [8]. The BER of a direct path is just the BER of the corresponding direct link BER_d as:

$$BER_{\text{direct}} = BER_{\text{d}} \tag{2}$$

The BER of a two-hop path is calculated as:

$$BER_{\text{two-hop}} = 1 - (1 - BER_1) \cdot (1 - BER_2) \tag{3}$$

where BER_1 and BER_2, are the BER of the first and second hop, respectively. Notice that this approach does not ensure that the chosen relay path delivers a higher throughput than the direct path, due to the store and forward behavior of the relay node. However, the lower BER increases reliability of the transmission.

Scenario size	$100m\ x\ 100m$
Mobility model	Random Waypoint (speed: $0.5 - 2m/s$)
Rice K-value	6 (based on [9])
Path loss exponent n	2.9 (based on [10] for outdoor measurements.)
Modulation scheme	BPSK (6 Mbit/s in 802.11a)
Noise floor	-86 dBm
Transmission power	100 mW

TABLE I
SCENARIO PARAMETERS.

III. METHODOLOGY

For evaluation we consider a three-step approach as sketched in Fig. 2. First a simulation of node mobility is generated based on the random waypoint mobility model. The outcome is a trace of the movements of all nodes. Now the ns-2 simulation[1] is executed, based on the mobility trace and the scenario specific parameters listed in Table I. We use the *802.11ext* module to simulate realistic 802.11a behavior. This ns-2 version includes a Nakagami fading model which has been parametrized according to Table I with model parameters $\Gamma = n$ and $m = \frac{(K+1)^2}{2K+1}$ to approximate a Ricean fading

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[1] The ns-2 simulation is based on [11], which has been updated with the authors' latest patch from October 21, 2008.

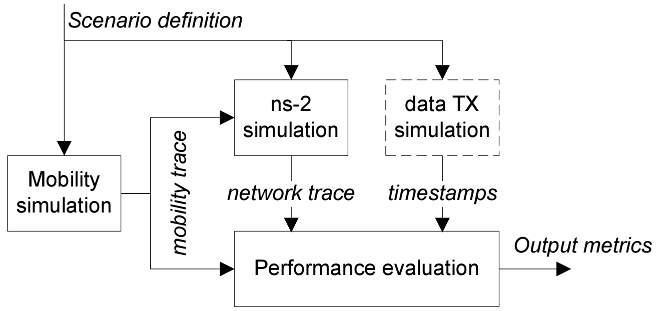

Fig. 2. Simulation overview.

environment with $K = 6$. Further, a custom ns-2 agent has been developed that initiates hello broadcasts periodically and upon reception of a hello frame, the agent creates a measurement frame and sends this to the AP. The outcome of the ns-2 simulation is a trace file that for every node describes when hello and measurement frames are received. Another trace file that specifies destination node and timestamp for the data transmissions is generated based on the defined transmission interval parameter μ_{tx}. The destination node is chosen randomly between all MDs for each transmission.

In this work the measurement collection and data transmissions are simulated separately in ns-2 and matlab, to make the implementation simpler and thus allow for rapid prototyping. The considered solution does therefore not take into account the mutual influence of the data transmissions and the measurement collection.

A. Performance evaluation

In order to evaluate the performance impact of mobility on the two-hop relay selection, we compare the measurement based approach described in section II to the case where the *direct* path is always used and to the *ideal* case where exact and updated link state information is always available. Further we calculate the following metrics:

a) Fraction of transmissions with different path: This metric expresses the fraction of transmissions where the ideal scheme and measurement based scheme have not chosen the same path. In other words, this corresponds to the fraction of transmissions where the measurement based approach makes a sub-optimal path selection. To see the actual penalty of sub-optimal path selections the avg. BER metric is used.

b) Avg. BER: This metric describes the average BER that is obtained for the data transmission for each of the three schemes: *measurement based*, *ideal*, and *direct*. The BER is as previously stated, calculated from the SNR using theoretical expressions from [8] given the BPSK modulation scheme and the Ricean fading model (K=6). The SNR that is needed to estimate the BER is calculated using the following steps: Node positions at transmission instants are obtained from the mobility model and the link distances are calculated as the shortest distance between all node pairs. Based on link distances, the path loss is calculated using the following path-loss model from [10]:

$$\overline{PL}(d)\ [dB] = PL(d_0)\ [dB] + 10n\log_{10}\left(\frac{d}{d_0}\right) \tag{4}$$

where $\overline{PL}(d)$ is the path loss in dB at the receiver, d is the distance between transmitter and receiver, $PL(d_0)$ is the path loss in dB at a reference distance $d_0 = 1m$, and n is the path loss exponent. Given a specific transmit power level P_{tx}, the calculated path-loss $\overline{PL}(d)$ and assumed noise floor N_{floor}, the SNR is calculated as:

$$SNR = P_{\text{tx}} + \overline{PL}(d) - N_{\text{floor}}[dB] \tag{5}$$

Having determined the SNR, the BER can now be calculated using theoretical expressions from e.g. [8].

IV. RESULTS AND DISCUSSION

The results have been created using the parameters and settings listed in Table I and Table II. The default parameters for the ns-2 802.11ext model have been used if not explicitly specified in the tables. The errorbar in the results show the overall mean and 95% confidence intervals for the mean values obtained in each simulation run.

Simulation time	$360s$
No. of simulation runs	15
Hello interval μ_{hello}	$5 \pm \text{uniform}(0..0.5)s$
Transmission interval μ_{tx}	0.5 s (exponentially distributed)
Storage time α_{store}	20 s

TABLE II
SIMULATION PARAMETERS

The first results in Fig. 3 show the achieved BER for varying number of MDs. We see that increasing the number of MDs does not have a practical impact on the relative performance of the ideal and measurement based schemes. However compared to the always direct scheme, the measurement based and ideal schemes are gaining better BER performance. This demonstrates that when the node density increases, further relay transmissions via short links are possible, which in turn leads to reduced BER.

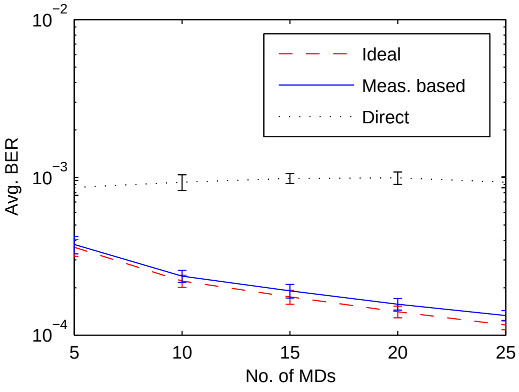

Fig. 3. Achieved avg. BER for varying no. of MDs.

The next set of results shown in Fig. 4 and Fig. 5 show the impact on the measurement based scheme of varying the hello interval μ_{hello} compared to the ideal and direct schemes. Fig. 4 specifically shows that as the frequency of hello broadcasts drops, the fraction of optimal path selections decreases. As a longer hello period increases the average age of measurements, it is also clear that a bigger fraction of sub-optimal path selections are made. In Fig. 5 we see that for $\mu_{\text{hello}} < 5s$, the achieved BER of the measurement based scheme is very close to the ideal scheme. As μ_{hello} increases, the measurement based scheme tends towards the direct scheme. It is also noteworthy that the BER never seems to increase above the level of the direct scheme. This can be explained by the fact that all measurements that are older than a predefined storage threshold are deleted and thus, they do not lead to an uncorrect decision. By applying such storage threshold the entries with the stale information are effectively discarded.

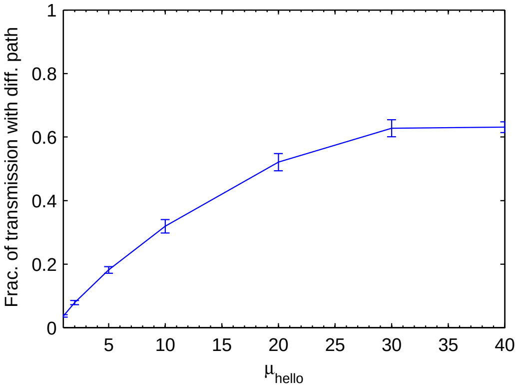

Fig. 4. Fraction of transmissions with different paths for varying μ_{hello}.

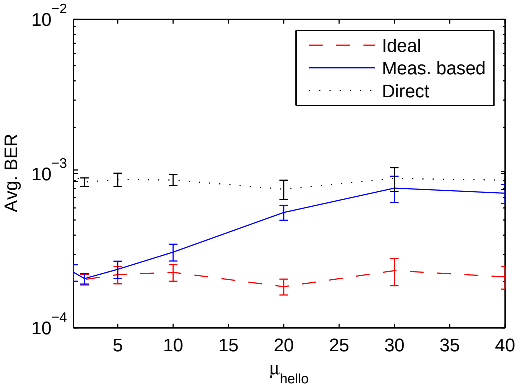

Fig. 5. Achieved avg. BER for varying μ_{hello}.

We now analyse how the mobility model impacts the path selection. Fig. 6 shows the fraction of different path selections and Fig. 7 shows the achieved BER when the speed of the mobile devices is increased. The x-axes in both figures represent the average speed according to Table III. Fig. 6 clearly shows that increasing the mobility speed leads to a higher fraction of suboptimal path choices for the measurement based scheme. This was also the case when varying the hello interval. However, though the curves in Fig. 4 and 6 are quite similar, the BER impact of varying the node speed shown in Fig. 7 is much more drastic. Here, the measurement based scheme achieves a significantly worse BER peformance than the direct scheme. This is of course highly undesirable, as the AP would be better off by using only direct transmissions. One obvious solution would be to increase the hello broadcast rate, as this would reduce the age of measurements. A downside to this is that the signaling overhead increases linearly with the hello broadcast rate. Increasing the broadcast rate is therefore costly in terms of capacity. We therefore investigate if limiting the storage time with the α_{store} parameter can improve this situation without increasing the signaling overhead.

	Speed [m/s]		
ID	min	max	avg.
1	0.5	2	1.25
2	2	8	5
3	5	15	10
4	10	20	15

TABLE III

MINIMUM AND MAXIMUM SPEED USED FOR THE RWP MOBILITY MODEL AND THE CORRESPONDING ID AND AVERAGE SPEED.

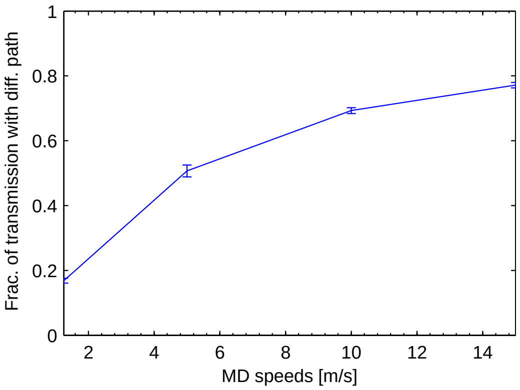

Fig. 6. Fraction of transmissions with different paths for varying mobility speed.

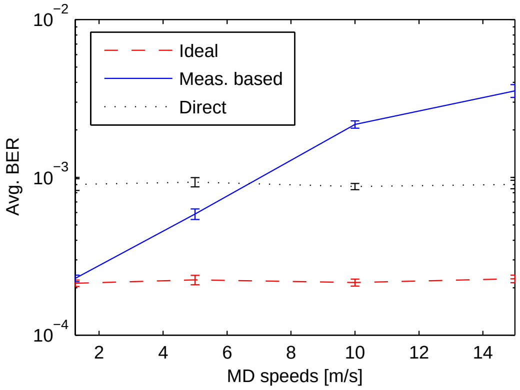

Fig. 7. Achieved avg. BER for varying mobility speed.

The results in Fig. 8 show the achieved avg. BER for the mobility model with parameters specified by ID 3 in Table III, which has a significantly worse performance than the direct scheme in Fig. 7. In Fig. 8 we see that setting $\alpha_{\text{store}} = 2s$ the resulting avg. BER is slightly lower than the direct scheme. Hereby we have shown that by proper setting of the α_{store} parameter it is possible to enhance performance without additional signaling overhead for a given scenario. As $\mu_{\text{hello}} = 5s$ in the considered scenario, setting $\alpha_{\text{store}} = 2s$ entails that the AP does not always have knowledge of a link, but measurements are only used when they are fresh, i.e. less than 2 seconds old. Further, as we consider symmetric links, both measurements from the two MDs of a link contribute to the AP's knowledge of a link. this means that the fraction of time where the AP has knowledge of a specific link, lies in the interval between $\frac{2}{5}$ and $\frac{4}{5}$, since hello broadcasts are unsyncronized and assumed to be i.i.d.

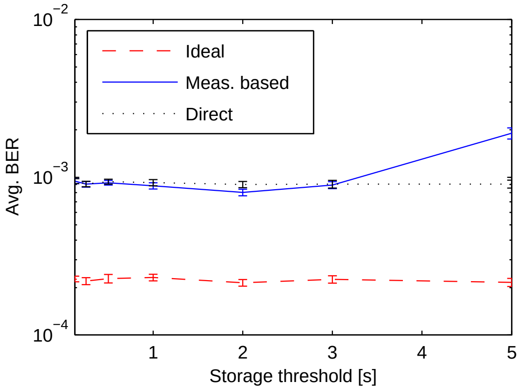

Fig. 8. Avg. BER for mobility model ID 3.

V. CONCLUSION

The scenario considered in this work concerns downlink data transmissions in a IEEE 802.11 based wireless network with mobile users. The focus of this work has been on analyzing the impact of node mobility on the path selection when either direct or two-hop relayed transmissions are possible for each data transmissions. The considered SNR measurement based scheme has been evaluated for the random waypoint mobility model using ns-2 and matlab simulations. Specifically we vary the number of mobile devices, their speed, the measurement frequency, and lastly the measurement storage time threshold. Results were compared to a scheme that always uses direct transmissions and an ideal scheme that has instant and perfect link state knowledge.

The results show that for relatively fast moving mobile devices ($5 - 15\ m/s$) the achieved avg. BER performance of the measurement based scheme can get significantly worse than the always direct scheme. Increasing the hello broadcast rate can mitigate this effect, however, at the cost of a linear increase in signaling overhead. We show that by limiting the measurement storage time, i.e. letting the AP use only fresh measurements, we are able to achieve a performance slightly better than or equal to the always direct scheme without increasing the signaling overhead. This result underlines the importance of choosing the storage threshold parameter carefully in scenarios with mobile devices. As the achievable BER performance for a given hello broadcast rate depends on the storage threshold parameter, these two parameters should be determined jointly when considering a given scenario.

An obvious point to investigate in future work would therefore be to consider the achievable benefit of jointly determining the hello broadcast rate and measurement storage time parameter. Here, an analytical model would be useful to quickly determine the best parameter values for a given scenario.

Another interesting future work topic would be to investigate measurement collection schemes that have a lower signaling overhead. One option, as briefly discussed in the paper, could be a scheme that accumulates a bulk of measurements before transmitting them to the AP. Also other types of measurements such as location information could be considered for path selection.

Currently the path selection criteria is based on BER. Though it reflects the path reliability, it would make more sense to use the expected throughput of the end-to-end transmission as a selection criteria. Finally, an option for future work would be to enhance the evaluation framework to take into account cross-influence between measurement collection and data transmissions.

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