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# Location-based Mobile Relay Selection and Impact of Inaccurate Path Loss Model Parameters

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**Abstract**—In this paper we propose a relay selection scheme which uses collected location information together with a path loss model for relay selection, and analyze the performance impact of mobility and different error causes on this scheme. Performance is evaluated in terms of bit error rate by simulations. The SNR measurement based relay selection scheme proposed in [1] is unsuitable for use with fast moving users in e.g. vehicular scenarios due to a large signaling overhead. The proposed location based scheme is shown to work well with fast moving users due to a lower signaling overhead.

The required location accuracy was found to be comparable to the accuracy of standard GPS. As the scheme was found to be highly sensitive to NLOS situations with unknown attenuation, knowledge of obstacle locations obtained either by sensing online or from a map of obstacles, was identified as a prerequisite in these situations. As the location-based scheme relies on a path loss model to estimate link qualities and select relays, the sensitivity with respect to inaccurate estimates of the unknown path loss model parameters is investigated. The parameter ranges that result in useful performance were found to be wide enough to allow them to be estimated in practical systems.

## I. INTRODUCTION

The distance between transmitter and receiver nodes is typically a major limiting factor for the performance of data transmissions in wireless networks. By introducing relaying techniques, nodes located between a transmitter and receiver can be exploited to provide a more reliable multihop path and/or a higher throughput to be achieved [2][3][4].

In this work we consider a wireless network where users are *mobile* and primarily need to make downlink transmissions, e.g. for audio or video streaming. We therefore consider *centralized* relay selection where transmissions are initiated from the access point (AP) and can be direct or via a two-hop relay path. Thus, the AP needs to determine the most appropriate transmission path of a packet to its destination given the spatial distribution of nodes at a given moment.

An existing relaying protocol for WiFi networks is the coopMAC protocol [5]. This protocol uses past observations of link quality for relay selection. As even slow movements of the potential relay nodes (max 1 m/s, 60 s pauses), will decrease the gain compared to standard 802.11 to less than 10%, the protocol has no practical benefit in mobile networks.

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Another relaying protocol is the CCMAC protocol [6] that aims at improving throughput for uplink transmissions in the region near the AP by allowing simultaneous source to relay transmissions. The authors do not consider the impact of mobility explicitly, but as this protocol, like the coopMAC protocol, uses historic link state information for relay node selection, we expect a significant gain reduction when used in mobile networks. The Harbinger protocol described in [7] is designed to cope with mobility. The protocol assumes that nodes are aware of their own 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 MAC 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. This approach is however not compatible with 802.11 networks with respect to rate adaptation and channel contention.

In previous work [1] we have shown that a proactive and centralized approach, where SNR measurements for links are obtained by periodic hello broadcasts and subsequently collected at the AP, is beneficial for mobile networks compared to existing protocols such as CoopMAC. However, we have noticed that the need for individual link measurements results in the signaling overhead growing nearly quadratically with an increasing number of mobile nodes. This makes it difficult to cope with dense high speed scenarios, as demonstrated later in section IV.

In this paper we propose a relay path selection scheme based on collected location information aiming at improving performance in highly mobile scenarios. This location based scheme requires only one location coordinate per node to be communicated to the AP, hence showing only linearly growing communication overhead for an increasing number of mobile nodes. However, as this scheme relies on potentially inaccurate location measurements and utilizes a path loss model to predict the link states, both the accuracy of the location measurements and the correspondance between the path loss model and the actual radio propagation environment will influence the goodness of the path selection. The movement speed, location measurement accuracy and path loss model parameters will therefore be the main evaluation parameters.

In section II we outline the considered scenario and describe

the path selection problem and considered schemes. 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 conclusion and outlook is given in section V.

## II. SCENARIO

As in our previous work in reference [1], we consider down-link transmissions from a fixed AP to mobile devices (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. The following criteria is used for relay path selection. The relayed transmission path is chosen if the condition in (1) is satisfied:

$$BER_{AP,r_{opt},D} < BER_{AP,D} \quad (1)$$

Where  $BER_{AP,r_{opt},D}$  is the BER of the two-hop path that delivers the lowest BER according to:

$$r_{opt} = \arg \min_r (1 - (1 - BER_{AP,r}) \cdot (1 - BER_{r,D})) \quad (2)$$

where  $BER_{AP,r}$  and  $BER_{r,D}$ , are the BER of the first hop from the AP to the relay  $r$  and second hop from the relay  $r$  to the destination  $D$ , 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.

For both schemes the procedures used to collect measurements are envisioned as L2 protocol extension. Further, since old measurements may be misleading due to mobility of the MDs, it is assumed that a parameter denoted  $\alpha_{store}$  exists in the AP, which expires measurements when their *storage time* exceeds  $\alpha_{store}$ .

### A. SNR-based scheme

The procedure of collection SNR measurements and estimation of BER is described in details in the previous paper [1]. In the following we will summarize the key points. Each MD broadcasts 20 octets hello frames every  $\mu_{hello}$  seconds. Upon hearing a neighboring MD's hello broadcast an MD will measure the SNR for that transmission and send this in a 28 octets measurement frame to the AP. This results in  $N$  hello frame transmissions and  $N(N-1)$  measurement frame transmissions every  $\mu_{hello}$  seconds under ideal conditions. Retransmissions due to collisions and hello broadcast reception errors may give slightly different numbers in practice. SNR measurements from the network links are finally converted into avg. BER estimates using theoretical expressions from reference [8] given the BPSK modulation scheme and the Ricean fading model ( $K=6$ ).

### B. Location-based scheme

The idea behind this scheme is that by knowing the locations of the MDs in the network, the path-loss, SNR and in turn the BER can be estimated with propagation models by assuming fixed transmit power and approximating noise floor

and propagation properties of the environment. Locations are obtained by letting all MDs transmit location measurements obtained from e.g. GPS receivers periodically with interval  $\mu_{loc}$  to the AP using unicast transmissions. Similarly to the case with hello broadcasts for the SNR measurement based scheme, the initial transmission time is chosen for each node uniformly random in the interval  $[0, \mu_{loc}]$ . Further, the following location measurement transmissions are offset with a uniform random jitter in the interval  $[-0.1 \cdot \mu_{loc}, 0.1 \cdot \mu_{loc}]$  to avoid transmissions being in sync. The measurement frame is a MAC control frame that carries the longitude (4 octets) and latitude (4 octets) of the node. Assuming the longitude and latitude are given as a degree decimal fraction and the circumference of the earth is  $40000km$ , the precision that is supported by this format is approximately  $\frac{40000km}{2^{24}} = 0.01m$ . The frame size amounts to 28 octets when adding longitude and latitude information to the standard 802.11 control frame layout [9]. This is the same size as the SNR measurement frame.

Having collected the MD locations, first the path-loss is estimated with this path-loss model from [10]:

$$\overline{PL}(d) [dB] = PL(d_0) [dB] + 10n \log_{10} \left( \frac{d}{d_0} \right) \quad (3)$$

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. As the value of  $n$  is scenario dependant and its exact value is typically not known in advance, we will investigate the sensitivity to inaccurate estimates of this parameter in section IV.

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:

$$SNR = P_{tx} + \overline{PL}(d) - N_{floor} - X [dB] \quad (4)$$

where  $X$  is a random variable representing shadowing due to obstacles in the environment. Initially we will assume  $X = 0$ , however in NLOS situations that we will investigate later in this paper it will be necessary to guess the attenuation. This is covered in section IV. Having determined the SNR, the expected BER can now be calculated using theoretical expressions from reference [8].

## III. METHODOLOGY

For evaluation we consider simulations of mobility and the wireless network followed by a combined performance evaluation as sketched in Fig. 1.

### A. Simulations

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<sup>1</sup> is executed, based on the mobility trace and the scenario specific parameters listed in Table I. We use the *802.11ext* module

<sup>1</sup>The ns-2 simulation is based on [11], which has been updated with the author's patch from October 21, 2008.

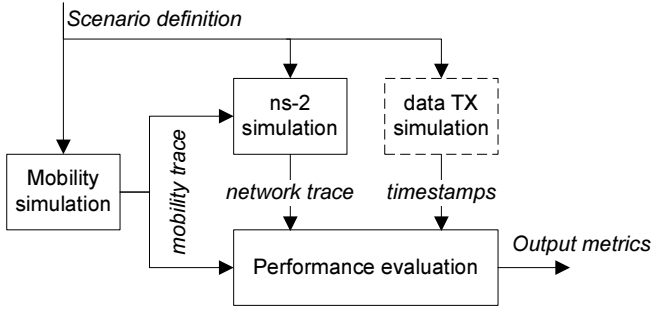


Fig. 1. Simulation overview.

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 environment. In addition to the existing ns-2 agent for generating and collecting SNR measurements from [1], we have added an ns-2 agent for collecting location measurements. This agent makes each MD transmit a measurement frame containing its location periodically as described in section I. We assume that MDs are equipped with GPS receivers that give the location coordinate  $(x + \epsilon_{\text{pos}}, y + \epsilon_{\text{pos}})$  where  $\epsilon_{\text{pos}}$  is a zero mean gaussian error with standard deviation  $\sigma_{\text{pos}}$  representing the GPS inaccuracy. 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  $\mu_{\text{tx}}$ . The destination node is chosen randomly between all MDs for each transmission.

Scenario size	100m x 100m
No. of mobile devices	10
Mobility model	Random Waypoint (speed: 2 – 8m/s)
Rice K-value	6 (based on [12])
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.

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 and a future work item is to take this interaction into account.

### B. Performance evaluation

In order to evaluate the performance of the proposed location measurement based path selection scheme, we compare the performance of this scheme to the following three schemes: the SNR measurement based scheme from reference [1], the

case where the *direct* path is always used, and the *ideal* case where exact and updated link state information is always available. We consider the following metrics:

a) *Avg. BER*: This metric describes the average BER that is obtained for the data transmission for each of the considered schemes. The BER is 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: 1) 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 and SNR are calculated using eq. (3) and eq. (4) and hereafter the BER is estimated using using theoretical expressions from e.g. reference [8].

b) *Signaling channel utilization*: This metric gives the overhead spent on obtaining and collecting measurements as a fraction of channel capacity. First, the transmission time  $t_{\text{tx}}$  of hello and measurement frames is calculated as a function of the number of MAC PDU bits  $N_{\text{MPDU}}$  according to the IEEE 802.11a specifications in [9]:

$$t_{\text{tx}} = t_{\text{symbol}} \left[ \frac{N_{\text{MPDU}} + N_{\text{service}} + N_{\text{tail}}}{N_{\text{DBPS}}} \right] + t_{\text{training}} + t_{\text{signal}} \quad (5)$$

Here  $N_{\text{MPDU}}$  represents  $N_{\text{hello}} = 20 \cdot 8$  bits for hello broadcasts and  $N_{\text{meas}} = 28 \cdot 8$  bits for SNR and location measurements.

Now the signaling channel utilization is estimated as in eq. (6) and eq. (7), where  $N$  is the number of MDs.

$$U_{\text{snr}} = \frac{N \cdot (t_{\text{tx}}(N_{\text{hello}}) + (N - 1) \cdot t_{\text{tx}}(N_{\text{meas}}))}{\mu_{\text{hello}}} \quad (6)$$

$$U_{\text{loc}} = \frac{N \cdot t_{\text{tx}}(N_{\text{loc}})}{\mu_{\text{loc}}} \quad (7)$$

The actual signaling channel utilization may vary slightly due to possible collisions and retransmissions.

## 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. Initially, we compare the

Simulation time	360s
No. of simulation runs	15
Hello interval $\mu_{\text{hello}}$	5 ± uniform(0..0.5)s
Location interval $\mu_{\text{loc}}$	$f(N, \mu_{\text{hello}})$
Transmission interval $\mu_{\text{tx}}$	0.5 s (exponentially distributed)
Storage time $\alpha_{\text{store}}$	20 s

TABLE II  
SIMULATION PARAMETERS IN ADDITION TO TABLE I.

overhead in terms of the channel utilization used for signaling for the SNR-based and location-based relaying schemes.

In Fig. 2 the channel utilization spent for obtaining and collecting SNR measurements for different hello broadcast

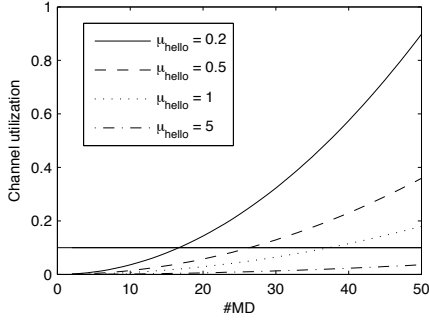


Fig. 2. Utilization of channel for obtaining and collecting SNR measurements (Data rate is 6Mbit/s).

intervals and node densities is shown. This has been calculated using eq. (6). As capacity should be used for data transmission and not spent as overhead for measurement collection, a utilization of more than 10% is considered unacceptable. In the plot we see that this limit is exceeded at slightly less than 40 MDs with  $\mu_{\text{hello}} = 1s$ . In vehicular scenarios where even faster updates are needed, we see that for  $\mu_{\text{hello}} = 0.5s$  and  $\mu_{\text{hello}} = 0.2s$  the utilization exceeds the 10% limit for just 25 and 18 MDs, respectively. This result emphasizes the need for a more efficient relay path selection scheme.

Turning our attention to the proposed location-based scheme, we see from the channel utilization plots shown in Fig. 3 that the used overhead is much lower for this scheme compared to the SNR-based scheme. The curves are calculated using eq. (7). Here, the 2% utilization is never exceeded in the plot, even when we have 50 MDs with measurement intervals of just  $\mu_{\text{hello}} = 0.2s$ , which lead to a utilization of 90% for the SNR measurement based scheme. This is mainly due to the fact that the utilization of the location based scheme grows linearly with the number of MDs whereas the growth is almost quadratic for the SNR based scheme.

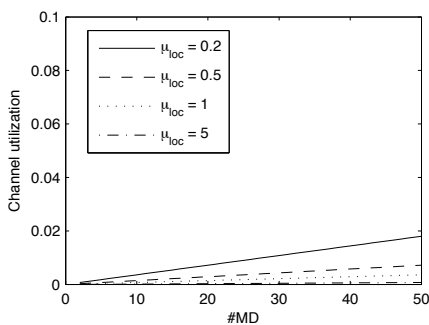


Fig. 3. Utilization of channel for obtaining and collecting location measurements (Data rate is 6Mbit/s). Notice this plot shows only 0 – 0.1 on the y-axis.

In the rest of this section we will investigate the impact of varying mobility speed, location measurement accuracy, and propagation model parameter accuracy for the proposed location-based scheme and compare the performance to the SNR-based, always direct and optimal schemes.

Fig. 4 shows that for the same measurement rate ( $\mu_{\text{hello}} =$

$\mu_{\text{loc}}$ ) the SNR and location based schemes perform similarly. However, if we instead use the  $\mu_{\text{loc}}$  that satisfies  $U_{\text{snr}} = U_{\text{loc}}$  (see eq. (6) and eq. (7)) the signaling overhead in terms of channel utilization will be the same for the SNR and location based schemes. The performance of the location based scheme will in this case be close to the ideal scheme.

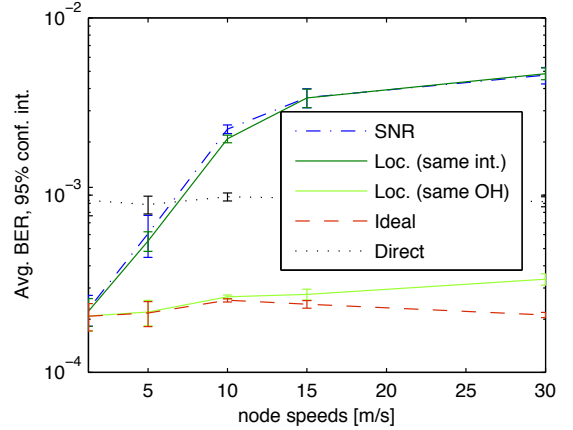


Fig. 4. BER impact of varying node speed.

As the accuracy of GPS location estimates depends on uncontrollable factors such as weather and surrounding buildings and therefore may vary, we investigate the achieved performance for different accuracy levels in Fig. 5. In this and the following plots the SNR based scheme has been generated for an average movement speed of  $5m/s$ . The path loss model used for the location based scheme uses the true path loss exponent  $n = 2.9$  in this plot. Fig. 5 shows that

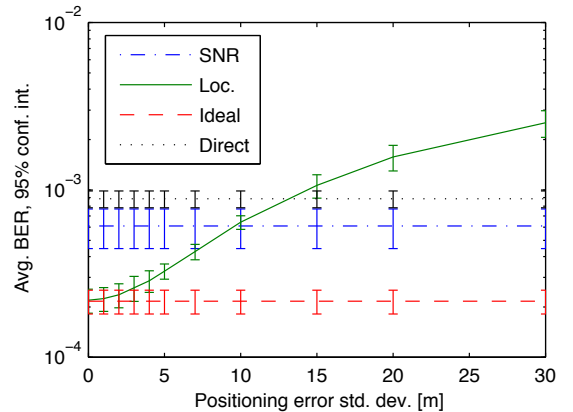


Fig. 5. BER impact of the accuracy of location measurements. Node speed is  $5m/s$ .

the location measurement based scheme performs close to the ideal scheme for  $\sigma_{\text{pos}} < 5m$ , while it is still better than the SNR based scheme up to  $\sigma_{\text{pos}} < 10m$  and becomes worse than the direct scheme when crossing  $\sigma_{\text{pos}} \simeq 13m$ . Considering that GPS receivers typically achieve an accuracy of  $15m$  [13], a GPS-only localization system may not be accurate enough for location based relaying. A solution would be to consider a hybrid localization approach using both GPS, Galileo and

network based localization techniques that have been shown to improve location accuracy in [14].

Since the path loss exponent cannot be assumed to be known, we investigate the impact of varying the guessed value of  $n$  in Fig. 6. Interestingly, the performance of the location

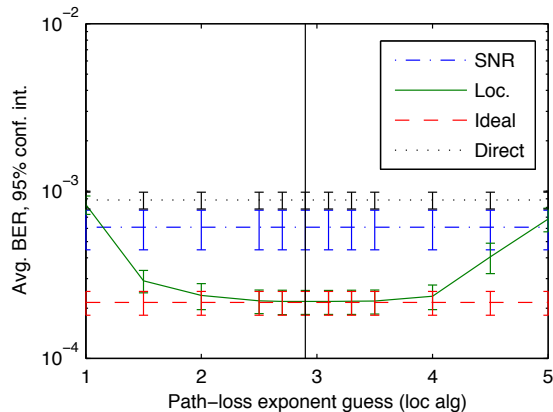


Fig. 6. BER impact of the accuracy of the used path loss exponent compared to the true value of 2.9. Node speed is  $5m/s$ .

based scheme is very close to the ideal scheme for values in a relatively wide range of  $2 < n < 4$ . Correct estimation of the path loss exponent does not seem to be highly important for achieving a near ideal performance with the location based scheme.

There may be cases where the direct propagation path between two nodes is blocked by obstacles. This NLOS condition may occur between two MDs or the AP and an MD. In this work we have introduced a horizontal "wall" that attenuates all crossing transmissions, but does not hinder node movements. In Fig. 7 we investigate the impact of varying the wall attenuation for a wall that is placed  $0.25m$  below the AP. That is, the AP has LOS to all MDs in the upper half of the scenario and NLOS towards all MDs in approximately the lower half.

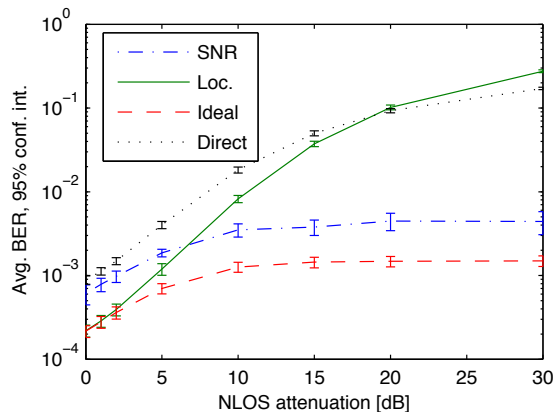


Fig. 7. BER impact from NLOS caused by horizontal wall for increasing attenuation. Node speed is  $5m/s$ .

All schemes achieve worse performance for increasing wall attenuation. However it is clear that the ability to sense the

wall attenuation that both the ideal and SNR based schemes have is useful, as their performance does not degrade as much as the location based and direct schemes. When transmitting to an MD in the lower half of the scenario, the direct scheme will experience the attenuation for all transmissions from the AP to such nodes, whereas the ideal and SNR based schemes can take the attenuation into account when selecting a relay node. Since the location based schemes uses only the path loss model for predicting link states, the wall attenuation is not taken into account and the relay can even be chosen in such unfortunate way that the wall is crossed in both the AP-relay and relay-destination transmissions. This can be seen in Fig. 7, where the BER of the location based scheme even exceeds the direct scheme.

Assuming that the AP has access to a spatial map of obstructions that cause NLOS conditions, the performance of the location based scheme can be improved in NLOS conditions. The map could be used to determine if there is LOS between two node positions. For LOS situations the attenuation term  $X$  in (4) is zero, while for NLOS it will be nonzero. But as the wall attenuation cannot be assumed to be known, we investigate the performance impact of different guesses for the attenuation value. We use a wall attenuation of  $13.3dB$  in our simulations, since according to reference [10] this value is typical.

Fig. 8 shows that as the NLOS attenuation guess gets close to the true value of  $13.3dB$ , the avg. BER of the location based scheme decreases. Guesses exceeding the true value do however not cause an increase in the BER. In addition

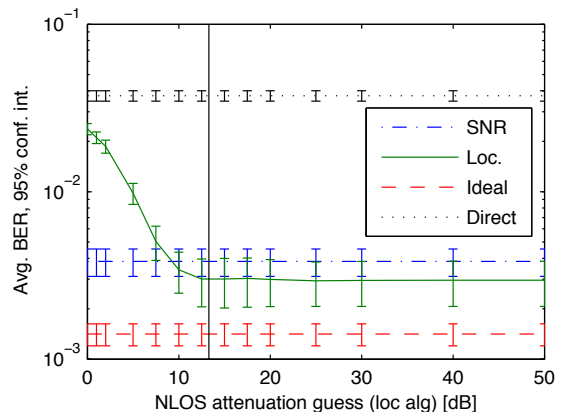


Fig. 8. BER impact for different guesses of the unknown NLOS attenuation with a true value of  $13.3dB$ . Wall is close to AP. Node speed is  $5m/s$ .

to the wall position  $0.25m$  below the AP, we also investigate the situation where the wall is half-way between the AP and the bottom border of the scenario, which corresponds to  $25m$  below the AP. This result is shown in Fig. 9. Primarily, we can see that the conditions have become difficult for even the ideal scheme as the BER has shifted a decade up, compared to Fig. 8. Further, it can be seen that under- or overestimation of the wall attenuation has a clearly negative impact on performance. So in this case, a priori knowledge of the wall attenuation is needed to obtain good performance. The wall

attenuation could be obtained by evaluating both SNR and location measurements in the online system, however this is a topic for future work.

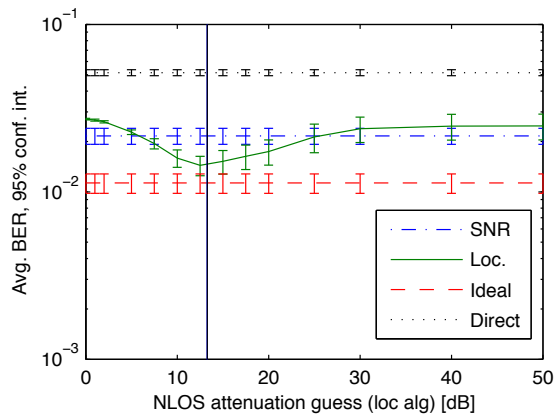


Fig. 9. BER impact for different guesses of the unknown NLOS attenuation with a true value of  $13.3\text{dB}$ . Wall is halfway between AP and bottom. Node speed is  $5\text{m/s}$ .

## V. CONCLUSION

The focus of this work has been on analyzing the performance impact of node mobility and incomplete information on relay path selection for downlink data transmissions in a IEEE 802.11 based wireless network with mobile users. Either direct or two-hop relayed transmissions are possible for each data transmissions. The SNR-based scheme proposed in [1] was found suitable for enabling relaying in mobile networks by frequently collecting link SNR measurements. However, in case of fast moving users, the measurement collection frequency that is required for acceptable performance results in a large signaling overhead.

In this work we have proposed a relay path selection scheme based which uses collected location information together with a path loss model for relay selection and thereby creates considerably less signaling overhead. We have shown that due to reduced signaling overhead, this scheme allows considerably higher movement speeds as compared to the SNR measurement based scheme proposed in [1]. In the considered case, a four fold increase of the movement speed was possible.

Further we found that the required location measurement accuracy was comparable to the typical accuracy of standard GPS systems. In many cases, a standard GPS system would therefore be usable, however, as the accuracy of GPS in urban/indoor environments is typically worse, a localization systems with a higher accuracy than standard GPS, should be considered for these cases. For example network based localization methods could be exploited to improve the localization accuracy.

As the parameters of the environment are not always known in advance, we have investigated the sensitivity of the location based relaying scheme towards inaccurate settings of parameter in the path loss model. With regard to the path loss exponent, which is typically either unknown and thus

guessed from the environment characteristics or estimated as the average over a larger area, we found that estimates within a relatively wide range of  $\pm 1$  around the true value resulted in near-optimal results. In the case of a NLOS situation, we found that the relaying performance was severely degraded without a priori knowledge. If on the other hand knowledge of LOS/NLOS between nodes was made available by extending the location based scheme with a spatial map of obstructions, the obtained performance was useful for estimates within  $\pm 3\text{dB}$  of the true attenuation factor. A hybrid scheme that combines the low overhead from the location based scheme with the sensing ability from the SNR based scheme would therefore be an interesting topic for future work.

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