# A Multi Hop Concept for HiperLAN/2: Capacity and Interference

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### Abstract

*In this paper the cellular aspects of a concept will be investigated that introduces a new element called forwarding mobile terminal (FMT) to the HiperLAN/2 (H/2) world. The FMT is designed to extend the area of an H/2 access point and provide users in uncovered areas with access to the fixed Internet by providing an intermediate hop. The FMT is a modified H/2 mobile terminal which only needs different software, but no additional transceiver. The contribution shows the behaviour of the above concept in different cellular environments regarding the interference situation and the effects onto the users. The concept is especially advantageous for environments where high attenuation by walls is expected. In city scenarios the forwarding concept allows a fast system roll-out while limiting the cabling cost and providing a reasonable user service in a large service area.*

## 1 Introduction

The access to the Internet has become a very important factor in recent years and it will become even more important in the future. At the same time the Internet goes wireless and systems are upcoming that support high data rates for the wireless access to the Internet.

Figure 1 shows users in private and public environments, where each user is equipped with a wireless terminal. Systems of this type include the *HiperLAN/2 (H/2) system* [1][2]. The H/2 system supports user data rates upto 40 Mbit/s. To support these data rates H/2 operates in the 5 GHz band with a bandwidth of 20 MHz per frequency channel.

The radio propagation in these frequency range is very much effected by high attenuation when line of sight can not be guaranteed in an environment, e.g., by walls. At the same time these systems are effected by system inherent interference when used as cellular systems. Since H/2 is operating in the unlicensed 5 GHz band interference might also result from non H/2 devices (e.g. IEEE 802.11a [9]).

In figure 1 the access to the Internet, resp. the *H/2 access point (AP)* for some users is provided by a multi hop link via an intermediate station. The equipment of these remote users is denoted as *remote mobile terminal (RMT)*. The term remote differentiates it from a standard *H/2 mobile terminal (MT)*, as the RMT does not have direct access to the AP. Intermediate stations that are forwarding the traffic for remote users are called *forwarding mobile terminals (FMT)*. These FMTs may also operate as conventional MTs.

In this contribution the H/2 Multi Hop Concept [3] is evaluated for its cellular capabilities namely the behaviour in

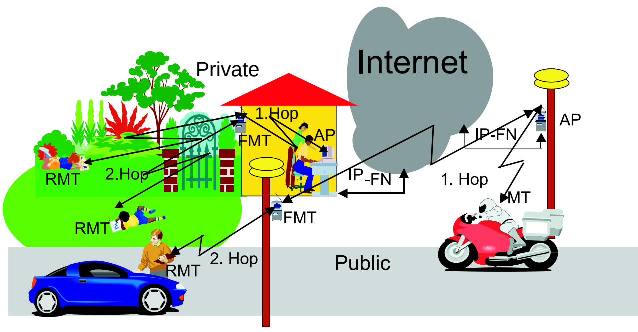


Fig. 1: Multi Hop Wireless Internet Public/Private

multi cell open space environments and city scenarios.

## 2 Implementation of H/2 Forwarding

The used time sharing approach for forwarding employs only a single transceiver and provides a solution with minor/no modifications to the existing H/2 specification in its basic implementation [3]. The FMT is simply a new element between AP and (R)MT, which is seen as an AP by the (R)MT and as an MT by the AP.

The natural place to integrate the time sharing forwarding concept in H/2 is the *medium access control (MAC)* sub layer, as this layer is responsible for a time division multiple access to the shared medium.

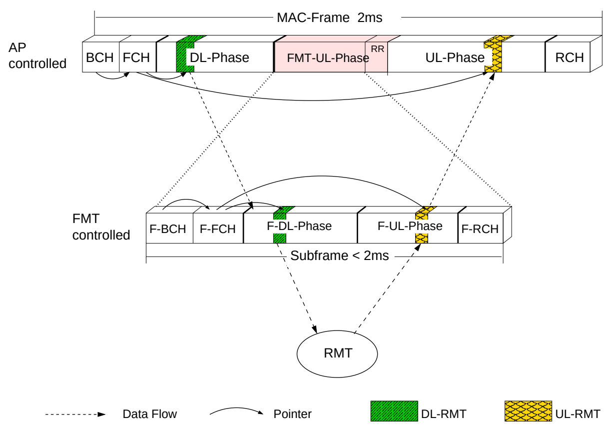


Fig. 2: H/2 MAC Frame including Forwarding Sub Frame Structures

Figure 2 shows the resulting MAC scheme. In the upper part the conventional *H/2 MAC frame (MF)* is displayed with its typical broadcast phase (BCH, FCH, ACH), downlink phase, uplink phase and random access (RCH) [4]. As it is a requirement to support regular MTs, a *sub frame (SF)* is generated by the FMT in its own uplink on the second hop. This SF has the same structure as the MF to allow access for conventional terminals.

## 3 Throughput in Various Environments

In the following figures the maximum End-to-End throughput possible for a single user is displayed against the distance from the AP. The curves show the maximum throughput for the H/2-system if a user is served with a single hop and the throughput possible for a two-hop connection using an FMT as an intermediate hop.

For the calculations the following attenuation model was taken into account [1]:

$$P_r = \begin{cases} P_s \cdot g_s \cdot g_r \left(\frac{\lambda}{4 \cdot \pi}\right)^2 \cdot \frac{1}{d^\gamma} & \text{for } d > 1m \\ P_s \cdot g_s \cdot g_r \left(\frac{\lambda}{4 \cdot \pi}\right)^2 & \text{for } d \leq 1m \end{cases} \quad (1)$$

with:
$P_s$ : Sending Power, $P_r$ : Received Power,
$g_s$ : Antenna Gain Sender, $g_r$ : Antenna Gain Receiver,
$d$ : Distance between Sender and Receiver,
$\lambda$ : Wave Length, $\gamma$ : Attenuation Factor.

The receive power budget $C/(I + N)$ is taken as input to calculate the packet error rate (PER) [5]. The PER is used to calculate the throughput taking into account an *automatic selective repeat automatic request (SR-ARQ)* protocol [1]. For the calculations in this section the following parameters were assumed:

| Parameter | Setting |
|---|---|
| Noise (N) | -90dBm |
| PER(C/(I+N)) | according to [5] |
| ARQ | hop wise selective repeat |
| Sending Power | 23dBm |
| Antenna Gain | 1 if not stated otherwise |
| $\lambda$ | for 5.3 GHz |
| $\gamma$ | 2.4, open space acc. [6] |

Table 1: Assumed Parameters for Throughput Calculations

Figure 3 compares a *line of sight (LOS)* one-hop configuration with a configuration having an FMT in the middle between AP and (R)MT. The gain is shaded. As the H/2 system has the opportunity to select from a number of PHY-Modes (resp. OFDM modulation and coding-schemes [4]), it can adapt to the current channel/transmission conditions of the system. For this reason the one-hop configuration always provides a higher data rate than the two-hop configuration. Except in an area between 200 and 250 m, which is caused by the fact that there seem to be no appropriate one-hop PHY-Mode from the available PHY-Modes. This graph

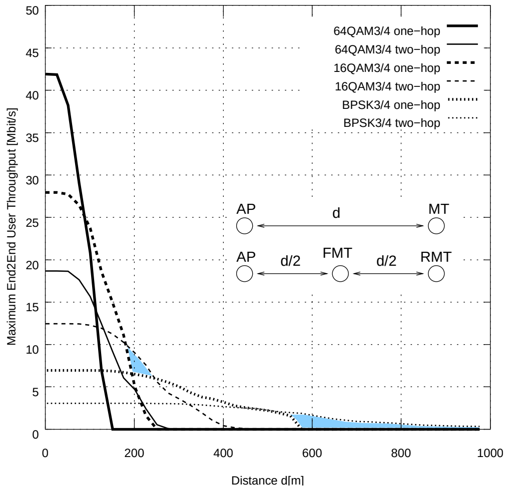


Fig. 3: Maximum Throughput using a Forwarder

shows, that for coverage extension in open scenarios (LOS) multi-hop solution may not be a promising way to go. The situation changes drastically if we consider obstacles in the way between AP and RMT. These obstacles can be overcome by the use of FMTs and two-hop communication.

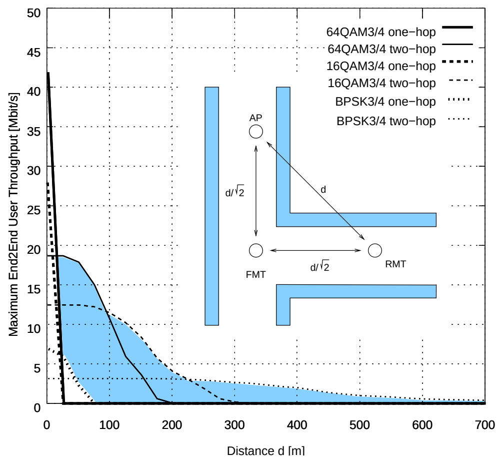


Fig. 4: Maximum Throughput using a Forwarder around a corner

Figure 4 shows this situation. The gain is again shaded. It becomes very obvious, that the multi-hop communication is well suited for areas in which we expect heavy shadowing by walls and/or obstacles (e.g. in office buildings). In public scenarios this situation will arise in housing areas. One of the most famous scenario of this type is the so called 'Manhattan-Scenario' [7]. The advantage of multi-hop communication further rises, if there are more walls to be overcome, i.e. the attenuation for the one-hop communication increases. In this analysis an attenuation of 11.8dB per wall was assumed [6]. In this scenario a planned multi-hop communication setup is assumed as suggested in [8].

## 4 INTERFERENCE

The results in the previous section were gained not taking into account the interference situation in an multi cellular environment. In the following the interference situation for the standard case of an open H/2 scenario will be analysed followed by an analysis of the forwarding case using 3 FMTs and city scenarios with 4 FMTs. Additionally the throughput performance and the quality of service parameter delay of user connections are investigated.

### 4.1 General Aspects

In figure 5 a co-channel interference reference scenario for a cellular system setup using 12 frequencies is displayed, i.e. setup with cluster size $N = 12$. The shaded cells operate on the same frequency and cause co-channel interference. For the evaluation the nearest 6 co-channel interferers of the inner cell are taken into account.

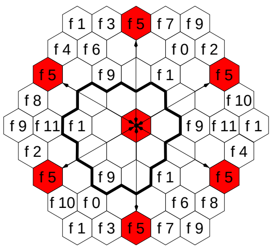


Fig. 5: Co-Channel Interference Scenario, Cluster Size N=12

The resulting *Carrier* $(C)$ to *Interference* $(I)$ and *Noise* $(N)$ - ratio is denoted by:

$$\frac{C}{I+N} = \frac{P_C}{N + \sum_{i=1}^{6} P_{I_i}} \tag{2}$$

with:
$P_C$ : Power Carrier, $P_{I_i}$ : Power Interferer $i$,
$P_N$ : Noise Power.

For system evaluation the $C/(I+N)$ - ratio is taken as input to denote the packet error rate [5] expected.

The simulations in this paper were done with a H/2 system simulator. Its structure is displayed in figure 6: with a geometrical description of the scenario, H/2 system parameter, the number and the position of the simulated entities a simulation scenario is generated. From the scenario the pathloss between all entities is calculated and stored in a table. Scenario and pathloss tables are then processed in a complex protocol simulation followed by a statistical evaluation which produces the characteristic system values. The system overall simulation parameters are summarised in table 2.

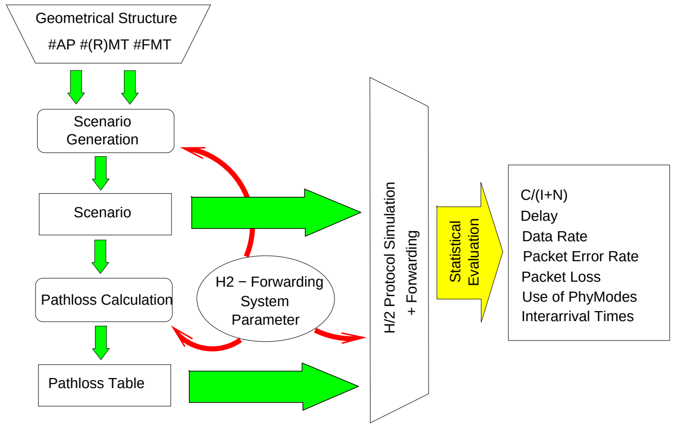


Fig. 6: MADCAT System Simulator Principle

| Parameter | Setting |
|---|---|
| Cell Radius each Entity | $50m$ |
| PhyMode | Link Adaptation |
| Scheduling | Exhaustive RR |
| Traffic Class (TP Dist.) | Best-Effort |
| Traffic Class (Delay Dist.) | Realtime |
| Number of simultanously active MTs | 60 |

Table 2: System Simulation Parameter

### 4.2 Standard H/2

Figure 7 shows the calculated maximum throughput for a cellular setup of an H/2 system with $50m$ cell size parameterized with the cluster size. With increasing cluster size the maximum transmission rate rises, as the co-channel interference is reduced with the distance between the interfering stations. The values for maximum transmission at the cell boundary are of particular interest, as these values show the

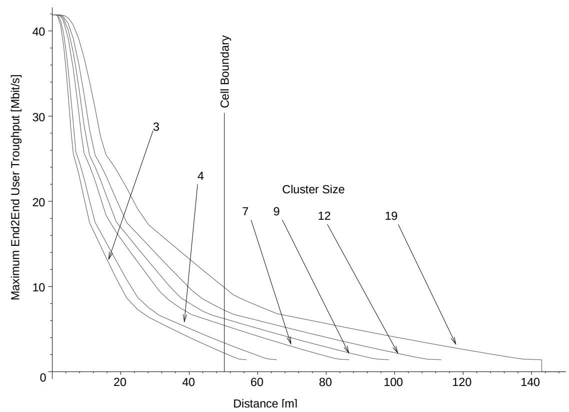


Fig. 7: Cluster Size vs. Throughput, Cell Radius $50m$

maximum throughput that can be expected and guaranteed by the network in a given system setup. In these calculations the interferer was assumed to be at the center of the cells. Reasonable cluster sizes for a system setup start with

7 to 9. The calculation is not only valid for H/2 but can also be taken as a figure for other 5 GHz systems (e.g. IEEE 802.11a [9]). Compared to the non interfering situation in figure 3 the influence of interference becomes very obvious. Figure 8 shows the simulated results for the throughput in an H/2 system. The small differences to figure 7 are caused by the assumption for the analytical evaluation that the interferers are located in the center of a cell. For the simulation the uplink was investigated, therefore most interferers were located more far away than the center of the interfering cell. This lead to a slightly higher mean throughput.

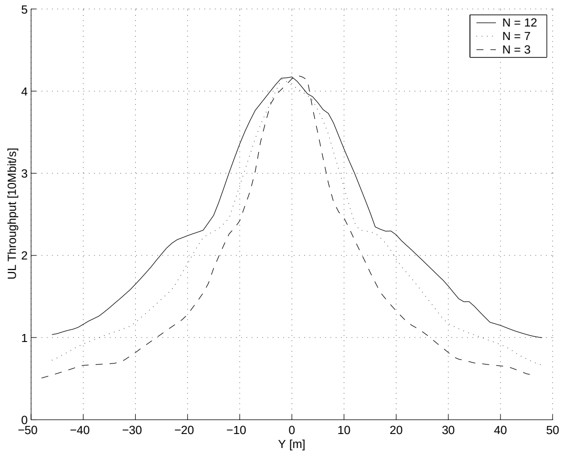


Fig. 8: Simulated max. Throughput vs. Cluster Size, Cell Radius $50m$, single MT

Besides throughput, quality of service measures like delay are important for user satisfaction. In figure 9 the simulation results for the delay of the user data packets for downlink traffic is shown. In the given scenario a homogeneous delay profile in the cell of about $1.4ms$ is observed. The difference in the delay reflects the better radio conditions with a higher cluster size as better PHY-Modes can be slected and the number of retransmissions is reduced.

### 4.3 H/2 Forwarding Open Space

The Forwarding concept for H/2 is aimed to support a cost efficient mechanism to provide service for H/2 users without the need to invest in expensive cabling of H/2 access points. In the following we will concentrate on the question how the service support will look like for the user in open space scenarios. In [8] it is already shown that the maximum gain for this concept in open space scenarios is achieved, if there are three forwarders which have no overlapping areas. This configuration is displayed on top right of figure 10. Additionally in figure 10 the cellular coverage using FMTs is displayed. The positioning of the basic forwarder cells with twelve frequencies is done analog to a standard cellular cluster of size twelve. Due to the shape of the basic cell the setup is slightly distorted.

In figure 11 a calculated $C/(I+N)$ ratio in a cellular forwarding scenario (cluster size $N = 12$) is displayed, as it is seen by a terminal. Besides the signal received from the AP the signal profile experienced along the x- and y-axis is shown. The distribution is no longer concentric around the AP and is caused by the setup as stated above.

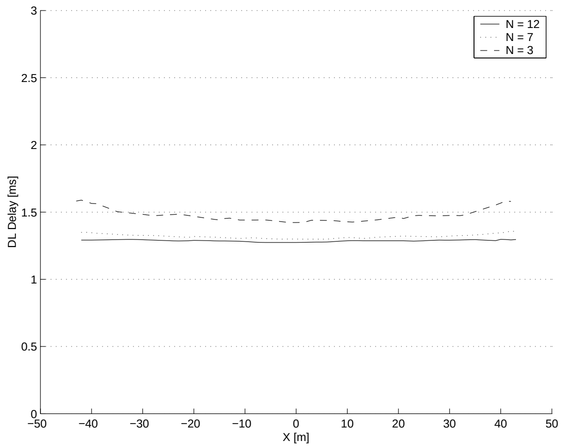


Fig. 9: Transfer Delay for the Standard H/2 Scenario, Cluster Size $N = 12$

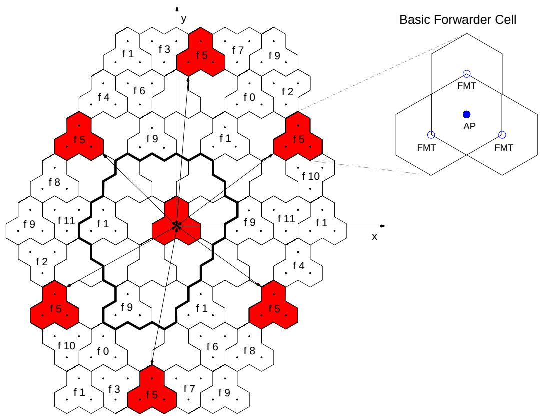


Fig. 10: Cellular Setup with 3 FMTs per Cell, $N = 12$

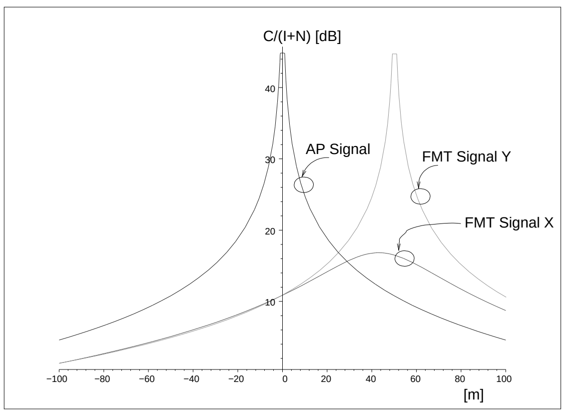


Fig. 11: Calculated $C/(I+N)$ Distribution in a Forwarding Scenario, Cell Radius $50m$

The association of terminals to either AP or FMTs is done based on the following assumption: upto the cell boundary ($50m$) the MT is associated with the AP. Outside this area the MT are associated with the FMTs and operate as RMTs (two-hop communication).

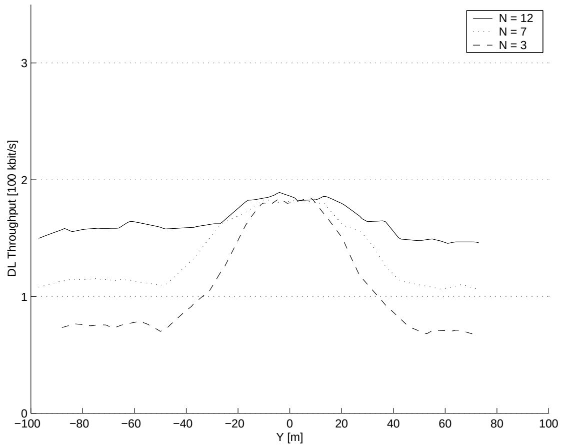


Fig. 12: Simulated Throughput Distribution in a Forwarding Scenario (Y-Direction), 60 MTs simultaneously

In figure 12 the throughput for the downlink of one of 60 simultaneously active terminals is shown for a simulation with the same parameters as for the H/2 standard case, see table 2.

For a cluster size of $N = 3$ and $N = 7$ the throughput decreases with the distance upto the point where a terminal is supported by an FMT (i.e. the MT becomes an RMT with a two-hop connection). At this point the FMT has the same connection quality towards the AP as an MT. Beyond this point the terminal can be supported by the FMT only with throughput as experienced by an FMT at the boarder of a cell. The interference situation for all terminals improves with an increasing cluster size. A cluster size of $N = 12$ nearly leads to a homogeneous traffic distribution in the cell. The total achieved system throughput is given in table 3.

| Cluster Size $N =$ | 3 | 7 | 12 |
|---|---|---|---|
| Throughput | 5.42 Mbit/s | 7.2 Mbit/s | 9.24 Mbit/s |

Table 3: Total System Throughput

In figure 13 the simulation results for the downlink delay are shown using the parameters from table 2. In this figure in the basic AP cell we find the delay distribution as already observed for the standard scenario. Additionally we find the mean delay distribution in the outer areas for a forwarding scenario (i.e. the delay as already known for the standard system plus the delay for an additional MAC frame). The parameters in this scenario where chosen in order not to overload the system. An increasing delay with an decreasing cluster size is observed, as the $C/I$ in larger clusters is better. Therefore better PHY-mode can be used and the retransmissions due to transmission errors is lower. The different delay level for each cluster size in the forwarding areas results from a fixed scheduling order for the position of the FMTs' subframes. Figure 14 gives an impression of the delay distribution over the whole cell area .

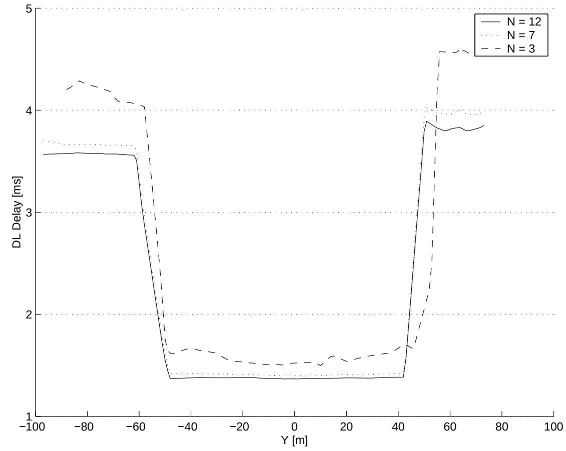


Fig. 13: Simulated Delay Distribution in a Forwarding Scenario (Y-Direction)

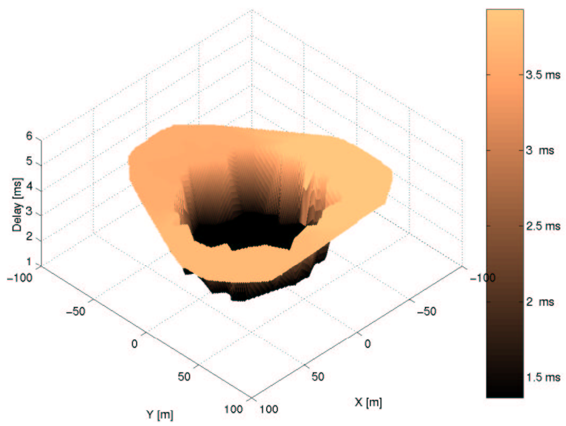


Fig. 14: Simulated Delay in a Forwarding Scenario, Cluster Size $N = 12$, Downlink

### 4.4 H/2 Forwarding in a Manhattan Scenario

As already announced in section 3 the H/2 Multi Hop Concept is especially beneficial for environment where heavy attenuation by walls is expected. In the following the so called 'Manhattan Scenario' as defined for UMTS [7] is taken as basis for investigations. As the H/2 is not designed for very large cells the setup with a block size of $75m$ x $75m$ with a street width of $15m$ is used.

In figure 15 possible distributions for standard H/2 APs in a Manhattan scenario are shown. In this configuration four frequencies are used. As the heavy attenuation by the walls is used to separate the cells, it is possible to use two frequencies in each direction alternatingly. The resulting re-use distance therefore results from the re-use in one direction (i.e. the streets). Figure 15 (a) shows a distribution of cells, where the AP are located between two blocks with a shift from street to street. This scenario is similar to the original UMTS scenario. Figure 15 (b) is a variant without shift from street to street. The interference to be taken into account for the system simulations only comes from cells and devices having LOS conditions.

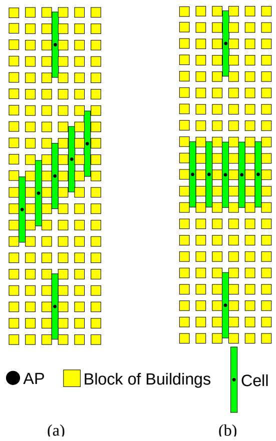


Fig. 15: Frequency Re-Use Pattern for Standard H/2, APs within Streets

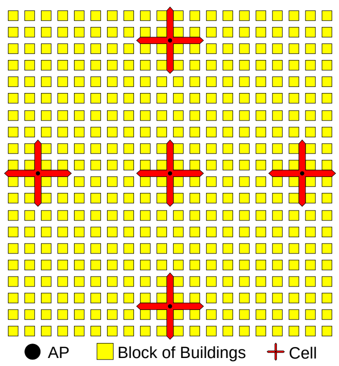


Fig. 16: Frequency Re-Use Pattern for Standard H/2, APs at Street Crossings

In figure 17 a setup is shown where each cell consists of one AP and 4 FMTs. In this case also the attenuation results in a situation where the interference comes only from cells which are in LOS conditions to the central cell. Therefore there are four interfering co-channel cells which are taken into account in the following. Only two frequencies are used for this scenario.

In figure 18 the throughput distribution for a single terminal of 60 simultaneously active terminals in the Manhattan scenario is displayed. The streets supported by FMTs are

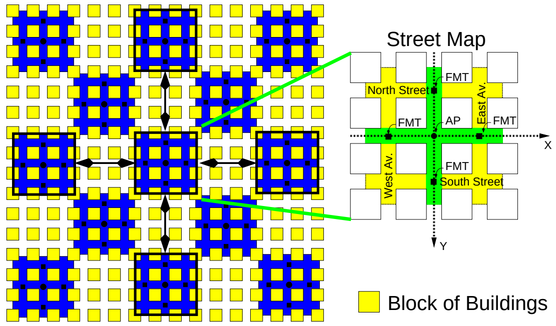


Fig. 17: Frequency Re-Use Pattern for H/2 Forwarding

supported with the same throughput as seen by an MT near to an FMT. This behaviour is identical to the open space forwarding scenario. With rising cluster size the throughput improves.

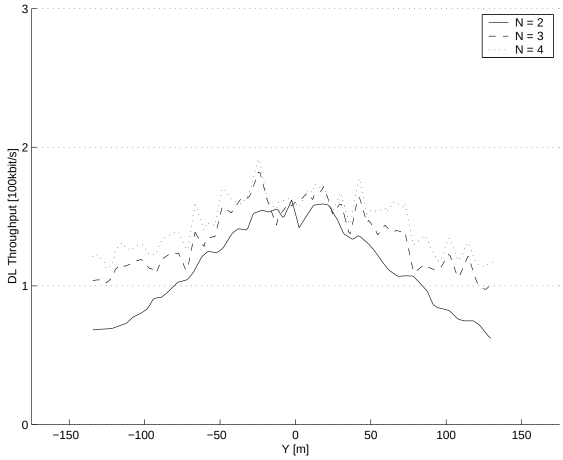


Fig. 18: Throughput Distribution for the Manhattan Scenario, 60 MTs simultaneously

In figure 19 the delay distribution is shown. It can be clearly seen which parts of the scenario are supported with a second hop. Users supported by a second hop will experience an additional delay as their data has to be transmitted twice. The difference between the different streets reflects the order the FMTs are scheduled. The crossing of the streets can easily identified, as the terminals on the crossings belong to two streets and are interpolated for each individual street. The FMTs can be identified at the point $streetlength = 0$ where users are served by the AP.

In table 4 the throughput for the different scenarios is displayed. As expected the forwarding scenarios have to share the resources for the different hops. Therefore the possible throughput is much lower. The forwarding on the other hand can operate with only two frequencies. This makes the initial setup very easy. With the forwarder concept it is possible to support a much bigger area without the need to install AP and their cabling.

There are a number of options to increase the capacity in forwarding systems. The numbers in brackets show the

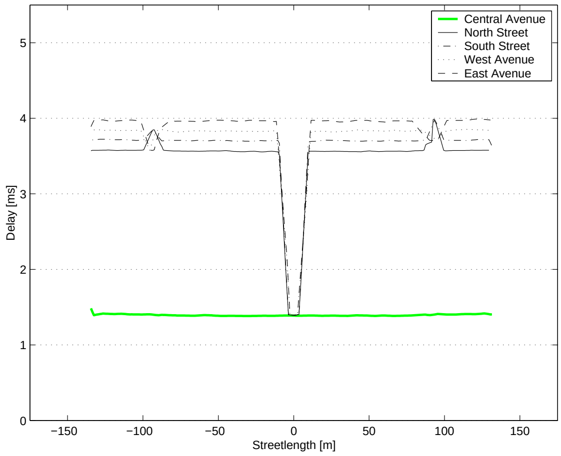


Fig. 19: Delay Distribution Downlink for the Manhattan Scenario

| Scenario | Freq. | Cell Size | Throughput |
|---|---|---|---|
| Fig. 15 (a) | 4 | $5400m^2$ | 19.0 Mbit/s |
| Fig. 15 (b) | 4 | $5400m^2$ | 18.0 Mbit/s |
| Fig. 16 | 8 | $10350m^2$ | 18.1 Mbit/s |
| Fig. 17 | 2 | $22255m^2$ | 6.3 Mbit/s (10.8 Mbit/s) |
| Fig. 17 | 3 | $22255m^2$ | 8.4 Mbit/s (12.0 Mbit/s) |
| Fig. 17 | 4 | $22255m^2$ | 9.2 Mbit/s (12.6 Mbit/s) |

Table 4: Throughput for Different Scenarios

throughput possible if directed antennas with $11.8dB$ gain are used between APs and FMTs. An other option is to use two or more frequencies in a forwarder cell. Furthermore it is possible to use special scheduling and exploit the attenuation of the blocks furthermore, i.e. send data in the East Av. and West Av. (refer to figure 17) at the same time.
Depending on the cost for investment either in devices or cabling, the desired user service, the number of available frequencies different setups may be chosen.
The forwarding concept for city scenarios allows a fast system roll-out while limiting the cabling cost and providing a reasonable user service in a large service area.

## 5 CONCLUSION

In this contribution an integrated multi hop communication concept for the *HiperLAN/2 (H/2)* system and the wireless Internet is analysed for its cellular capabilities rsp. the interference situation, the resulting capacity and quality of service for users. The concept is intended to be used for the infrastructure mode of H/2 as it aims to provide far remote users with a cost efficient access to the Internet without the need to invest into fixed infrastructure. The concept is especially beneficial for environments where high attenuation by walls is expected. In city scenarios the forwarding concept allows a fast system roll-out while limiting the cabling cost and providing a reasonable user service in a large service area.

## 6 ACKNOWLEDGEMENT

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