Capacity of a Relaying Infrastructure for Broadband Radio Coverage of Urban Areas

Tim Irnich, Daniel C. Schultz, Ralf Pabst, Patrick Wienert
Chair of Communication Networks (ComNets), Aachen University (RWTH)
Kopernikusstr. 16, D-52074 Aachen, Germany, phone +49 241 8027928, fax +49 241 8022242
Email: {*tim*|*dcs*|*pab*|*pat*}@comnets.rwth-aachen.de

***Abstract*— Owing to the difficult propagation conditions in the frequency range of future cellular broadband radio systems, very small cell sizes and high attenuation through obstacles (sufficient C/I ratio only in direct Line of Sight (LoS)) are expected to constitute a major challenge for the development of such systems. Thus, complete coverage of urban areas using a conventional (one-hop) cellular infrastructure is expected to be very costly due to the high number of base stations and fixed network connections needed. For this reason, the introduction of relaying is widely accepted to be an essential element in the development of future cellular broadband radio networks. This paper presents a methodology to quantify the influence of relaying on the capacity of a single base station. We define the capacity as the aggregate downlink throughput that is achieved by all users in the cell. Inspired by the well-known Wireless Media System (WMS) architecture [1][2], we compare the capacity of a conventional one-hop cellular architecture with the capacity of a configuration consisting of one base station and four regenerative Fixed Relay Stations (FRS) that together cover the same area like five base stations in a conventional cellular architecture. The presented methodology allows to explore the parameter space, which is spanned by system parameters like antenna gain, scenario geometry, noise and transmit power.**

I. Introduction

Future broadband radio interface technologies and the related high multiplexing bit rate will dramatically increase the traffic capacity of a single Base Station (BS), so that it is deemed very unlikely that this traffic capacity will be entirely used up by the user terminals roaming in the cell [3]. This effect will be amplified by the fact that future broadband radio interfaces will be characterised by a very limited range due to the very high operating frequencies which can be expected from such systems. Furthermore, future broadband radio interfaces will be characterised by high attenuation due to obstacles, leading to big areas that are shadowed from the BS.

An innovative solution to this class of problems is to trade capacity against range by introducing a number of Relay Stations (RS), which serve to enlarge the coverage area of a BS [4][5]. This is achieved by introducing a receive antenna gain (RX gain) at the RS, enabling the RS to connect to the BS in a distance outside the coverage area of the BS, and/or to receive from the BS at a data rate that is substantially higher than without RX gain. This concept will also solve the attenuation problem in a cost efficient way by extending the range of the BS to areas behind obstacles.

In this context we address the question of how the multiple transmission of user data caused by the relaying approach affects the capacity that is available in the coverage area of one BS. We present a methodology for calculating the capacity of a configuration called *2-Hop-Cell*, which is based on the relation between throughput and distance. This relation is derived from the well-known link-level simulation results presented in [6] by assuming an ideal SREJ-ARQ protocol. We then extend this relation to areas covered by a RS by calculating the resulting throughput that can be achieved when user data is transparently transmitted via one of the RSs.

Based on the assumption of

- uniformly distributed users in the cell's coverage area,
- a given user density
- and equal traffic offer per user

we determine the cell capacity, which is defined as the aggregate downlink throughput of all users served by the cell.

For the purpose of clear terminology we introduce the following:

- Access Point (AP): a BS that is directly connected to the fixed network.
- Fixed Relay Station (FRS): a BS connected wirelessly to an AP. An FRS appears to the terminals in its service area like a BS.
- Mobile Terminal (MT): the user's end device
- Media Point (MP): generic term for both FRS and AP

A. Ad-hoc relaying vs. infrastructure-based relaying

The idea of multi-hop transmission originates from the research area of ad-hoc networking, nevertheless it is very important to clearly distinguish between ad-hoc networking and relaying. Ad-hoc networking is predominantly characterized by an a priori *unknown and dynamic topology*, while relaying simply means that user data is transmitted more than one time before it reaches its destination node. Relaying is part of most ad-hoc networking approaches, but in our scope it is considered to be part of

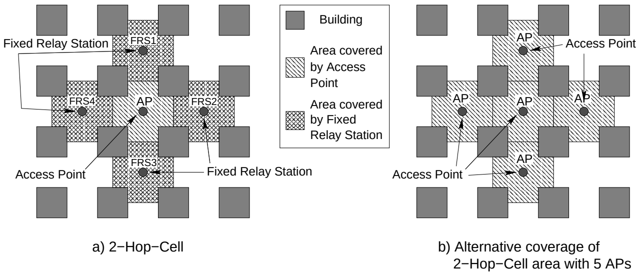


Fig. 1. Schematic view of a 2-hop-cell in a Manhattan scenario

a *fixed and planned topology.* The important difference in this case is that the routing matrix is known and remains constant over time, so that certain benefits of multihop relaying can be exploited to a significantly larger extent.

B. Related work

An introduction into the area of multihop transmission in cellular networks, including the introduction of a clear terminology, is provided by [7].

The scenario that is regarded in the scope of this paper is based on the well-known Wireless Media System (WMS) architecture. A detailed description of this architecture, which covers significantly more complex scenarios than our relatively simple 2-Hop-Cell scenario, can be found in [1] and [2].

The most widely known approach to calculate the capacity of wireless networks has been introduced by Gupta and Kumar [8]. One reason for us to choose a different approach is that Gupta and Kumar assume a wireless network without centralized control, where all nodes randomly access a common radio channel. Within our scope, presence of a central radio resource management for the coverage area of one AP (including the areas covered by the AP's FRSs) is foreseen. It is immediately clear that the question of how much traffic can be carried by a given configuration has to be adressed completely different under the presence of a centralized scheduling instance. The second reason is that Gupta and Kumar aim at general network topologies, which can be arbitrary and randomly chosen. Our research considers relaying in a fixed and planned infrastructure, where the topology of the infrastructure elements is known and constant over time. Therefore our approach was selected with respect to the possibility to incorporate these aspects.

II. Scenario and System Architecture

In the scope of this paper we focus on application of multihop relaying concepts in urban scenarios, which are widely agreed to be well represented by a Manhattan-type scenario [9]. Fig. 1 shows a schematic view of the radio coverage in a city center that is based on one AP, which is connected to the fixed network, and four FRSs that connect wirelessly to the AP. We call this configuration a *2-Hop-Cell.* A MT roaming around the area covered by the 2-Hop-Cell is served by the closest FRS or AP.

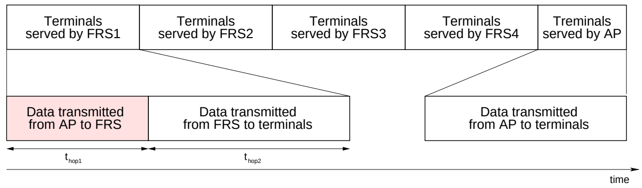


Fig. 2. Relaying in the time domain with TDMA scheme of sub-cell scheduling

The same area that is covered by the 2-Hop-Cell can be covered using an array of 5 BS as part of a conventional cellular (one-hop) architecture, by replacing each FRS with an AP. We will compare the 2-Hop-Cell with such a configuration in a way that these 5 BSs share the same amount of frequency spectrum that is available for the operation of the 2-Hop-Cell. This means that one of these BSs either has only a 20% share of the total available spectrum, or that the 5 BS have to be multiplexed in the time domain, both of these alternatives are equivalent to our analysis.

As our approach requires a given relation between Packet Error Ratio (PER) and Signal to Noise Ratio (SNR), we assume a fictitious multi-hop system that uses the same physical layer as it is used in the HiperLAN/2 or IEEE 802.11a system. The relation $PER = f(SNR)$ is taken from the well known link level simulation results presented by Khun-Jush et. al. [6] for a 5GHz Hiperlan/2 system with 20MHz channel bandwidth. As this physical layer consists of several parameter sets, each resulting in a different physical layer bit rate (these parameter sets are called *PHY-modes*), we assume ideal link adaptation, which means that at any time the PHY mode that delivers the best possible throughput is chosen automatically.

A. Time-domain forwarding and TDMA

We assume forwarding in the time domain, i.e., a packet that is addressed to a FRS-served MT is first transmitted from the AP to the FRS and afterwards forwarded to the MT using the same frequency channel; see Fig. 2. Furthermore, we assume a pure TDMA scheme without any kind of *optimized* scheduling for the coordination of the four FRSs, which means that our capacity figures do not contain the potential benefit of, e.g., sending packets from AP to one FRS parallel to the transmission of packets from another FRS to one of the MTs served by this FRS. We selected this viewpoint because it leads to a *lower bound estimate* of the capacity. For a discussion of the improvements that can be achieved by using by optimized scheduling strategies please refer to [10].

III. Relay Throughput Calculation

In the scope of this paper we regard two path radio propagation (see [11]), which is modeled by:

$$P_R = P_S \cdot g_S \cdot g_E \cdot \left(\frac{\lambda}{4\pi}\right)^2 \cdot \frac{1}{d^\gamma}. \tag{1}$$

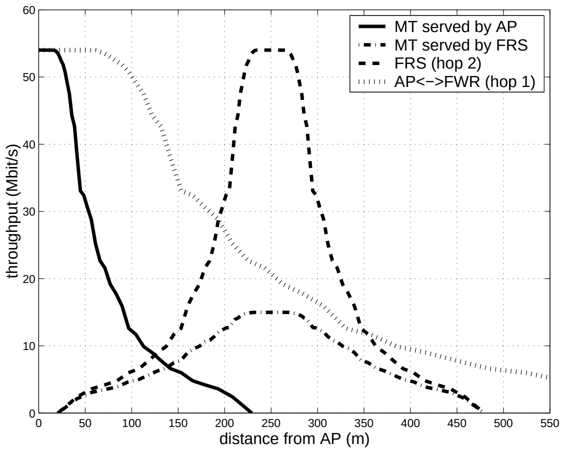


Fig. 3. Throughput for separate hops and end-to-end for MTs served by FRS (16 dBi FRS receive antenna gain)

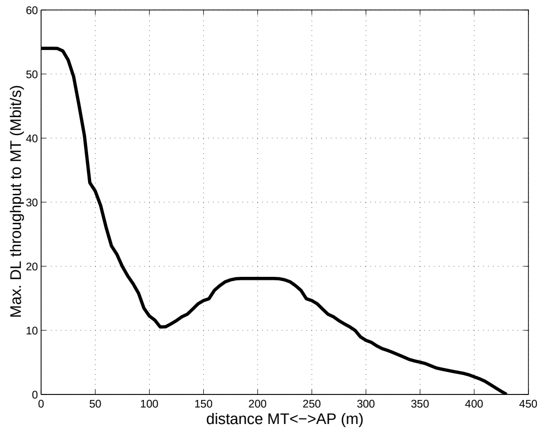


Fig. 4. Throughput-distance relation used for capacity evaluation (16 dBi FRS receive antenna gain)

We calculate the distance where a given SNR is valid, which leads to a relation between PER and distance from the BS. In the next step we assume an ideal SREJ-ARQ protocol, and calculate the resulting relation between throughput and distance from the BS; see the solid curve in Fig. 3. Any protocol overhead has been neglected for our calculations. Furthermore, no interference has been included. Radio coverage of BS and FRSs is assumed to be only straight ahead without coverage around corners (direct LoS).

We assume that the FRSs are equipped with directed transmit/receive antennas. This is a reasonable assumption, since the AP's location can be assumed to be known by the FRS. This results in an improved throughput-distance relation between AP and FRS, as denoted by the dotted curve in Fig. 3. The troughput between the FRS and a MT that is served by the FRS (dashed curve in Fig. 3) in general obeys the same throughput-distance relation like for transmission between AP and MTs served by the AP.

To calculate the throughput between AP and a MT that is served by a FRS we proceed as follows. Let TP_{hop1} denote the transmission rate on the first hop (AP to FRS), which is determined by evaluating the dotted curve in Fig. 3 at the given FRS location. Further let $TP_{hop2}(d)$ denote the transmission rate on the second hop (FRS to MT), depending on the distance between FRS and the regarded MT, d, which is given by the dashed curve of Fig. 3. The transmission durations of a packet size P are $t_{hop1} = {}^{P}/_{TP_{hop1}}$ and $t_{hop2} = {}^{P}/_{TP_{hop2}(d)}$. The total duration of a two-hop transmission, $t = t_{hop1} + t_{hop2}$ then leads to the relation between offered throughput by a FRS and distance between MT and AP:

$$TP_{FRS} = \left(\frac{1}{TP_{hop1}} + \frac{1}{TP_{hop2}(d)} \right)^{-1} \tag{2}$$

This relation is depicted by the dashed-dotted curve in Fig. 3. We now define the border between the AP's coverage area and the FRS's coverage area to be exactly the point where the solid curve meets the dashed-dotted curve, which is equivalent to the assumption that an intra-2-Hop-Cell handover from AP to FRS is performed when the achievable FRS throughput exceeds the AP throughput. If we now take the envelope of these two curves, this relation defines the maximum achievable throughput at any location in the 2-Hop-Cell coverage area. This figure, called TP_{max} in the following, is shown in Fig. 4.

IV. Cell Capacity

In the case where only one user is present in the cell, the cell's capacity is given by the maximum throughput this user is able to achieve. This throughput depends on the user's location, as described in the previous section. A single user can no longer maintain this throughput if the capacity has to be shared between several users, because only one user can transmit at a time, and the others have to remain silent (TDMA system). Thus, time represents the critical resource that has to be shared.

Assume two MTs at distances d_1 and d_2 with equal offered traffic A. The achievable throughput of these MT's at d_1 and d_2 is denoted by $TP_{max}(d_1)$ and $TP_{max}(d_2)$. Transmission of P bytes of data then takes $t_1 = {}^{P}/_{TP_{max}(d_1)}$ and $t_2 = {}^{P}/_{TP_{max}(d_2)}$, respectively. As these two transmissions have to take place one after another, the total service time for *both* MTs is $t = t_1 + t_2$. If we now conceive this service time as the duration of a fictious scheduling period, $P = P_{max}$ denotes the maximum amount of data that each MT can transmit in one scheduling period. Note that this offered traffic can also be normalized to different durations, so that it is not necessary to assume a certain duration of the scheduling period itself. The maximum traffic offer per user then computes to

$$A_{max} = \left(\frac{1}{TP_{max}(d_1)} + \frac{1}{TP_{max}(d_2)} \right)^{-1} = \frac{P_{max}}{t} \tag{3}$$

If we now extend the calculation to N MTs located at distances d_i, $i = 1..N$, the maximum traffic offer *per user* is

$$A_{max} = \left(\sum_{i=1}^{N} \frac{1}{TP_{max}(d_i)} \right)^{-1} \tag{4}$$

and the total transmit capacity of the cell is

$$C = N \cdot A_{max} = \frac{N}{\left(\sum\limits_{i=1}^{N} \frac{1}{TP_{max}(d_i)} \right)}. \tag{5}$$

Please note that this relation also holds for the case that not all of the N users are served by the same MP, the only prerequisite is that each of the distances d_i has its corresponding throughput value $TP_{max}(d_i)$, and that the transmission intervals of multiple users are sequential, i.e., no overlapping transmissions are taking place.

A. Distances d_i for uniformly distributed users

Obviously the capacity calculated according to (5) is unique for one specific spatial distribution of users in the cell's coverage area.

In the scope of this paper we assume that the users are *uniformly distributed* in the coverage area, with an average of N_u users per square meter. The area that contains an average of one user is denoted by $A_{user} = {}^1/_{N_u}$.

To obtain the d_i, we divide each sub-cell area into concentric circles, so that the area between to circles with radii r_i and r_{i+1}, respectively, is equal to the area that contains an average of one user, $A_{i+1} = A_i + {}^1/_{N_u}$, $A_1 = {}^1/_{N_u}$; see Fig. 5. This way we separate the coverage area of each MP into sub-areas that each contain one user only. We further assume that the user that belongs to one of these areas is located on the outer border side of the ring ($d_i = r_i$).

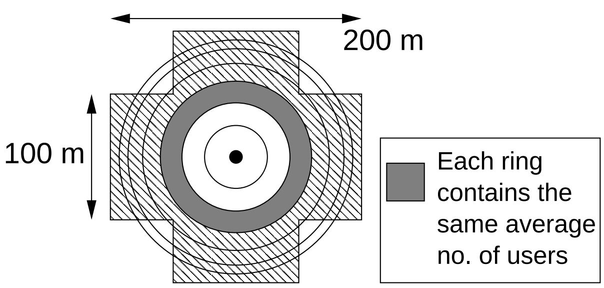


Fig. 5. For radii calculation the cell area is divided into concentric ring-shaped areas that contain one user each

The resulting rings are only complete until the outer radius of one of them reaches the building corners. This fact is included in the subsequent calculation of the radii of equal area rings.

Please note that, since the throughput-distance relation is axially symmetric, only the distance between the serving MP determines which throughput is actually received, so that a unique throughput value can be assigned to each d_i (see Fig. 4).

Since the area regarded for the d_i only comprises one sub-cell, up to this point the capacity that is obtained from (5) for this set of distances is only valid for the case that the whole 2-Hop-Cell capacity is *exclusively* assigned to the users of *one* sub-cell. Calculating the capacity of the 2-Hop-Cell for the case that the users of all sub-cells are sharing the capacity the same way would require separation of the whole 2-Hop-Cell area into concentric circles as well. This would lead to a very complex geometrical problem. We select a more elegant approach, which allows us to derive the 2-Hop-Cell capacity from the previously obtained sub-cell capacity figures.

B. 2-Hop-Cell capacity

An elegant way to determine the 2-Hop-Cell capacity is to derive relations between the five sub-cell capacities, which can be obtained by the method described abvove, and the 2-Hop-Cell capacity. The sub-cell capacities of the central sub-cell (served by the AP) and the relaying sub-cells (served by a FRS) are

$$C_{AP} = \frac{N_{sc}}{\sum\limits_{j=1}^{N_{sc}} \frac{1}{TP_{AP}(d_j)}} \tag{6}$$

and

$$C_{FRS} = \frac{N_{sc}}{\sum\limits_{k=1}^{N_{sc}} \frac{1}{TP_{FRS}(d_k)}}. \tag{7}$$

We define two strategies the AP's capacity can be shared by the five sub-cells in the 2-Hop-Cell coverage area:

1) Equal time share: each of the five sub-cells receives an equal fraction (i.e., 20%) of time for serving its users. In this case the capacity that is available in each sub-cell is reduced to 20 % of its original value, because every single throughput value $TP_{max}(d_i)$ in (5) is reduced to 20 % of its original value as well. Thus, the total 2-Hop-Cell capacity is equal to 20% of the sum of the sub-cell capacities

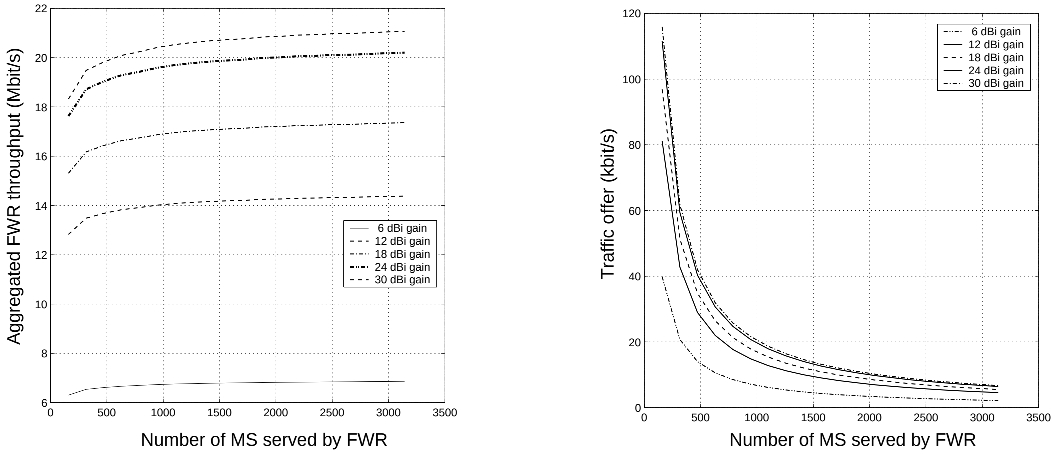
$$C = \frac{(C_{AP} + 4 \cdot C_{FRS})}{5} \Leftrightarrow \frac{1}{C} = \frac{5}{(C_{AP} + 4 \cdot C_{FRS})}, \tag{8}$$

where C_{AP} and C_{FRS} denote the sub-cell capacities of AP sub-cell and FRS sub-cells, respectively.

2) Equal capacity share: each sub-cell receives an equal share of capacity, which, due to the lower throughput values in the FRS sub-cells, means that the service intervals for the FRS sub-cells have to be longer than for the AP sub-cell.

We divide the number of uniformly distributed users in the whole 2-Hop-Cell area N into 5 equal parts, $N = 5N_{sc}$, where N_{sc} is the number of users located in one of the five sub-cells. According to (5) the total capacity of the 2-Hop-Cell then can be written as

$$C = \frac{5N_{sc}}{\sum\limits_{j=1}^{N_{sc}} \frac{1}{TP_{AP}(d_j)} + 4 \cdot \sum\limits_{k=1}^{N_{sc}} \frac{1}{TP_{FRS}(d_k)}}. \tag{9}$$



(a) Capacity vs. user density

(b) Traffic offer per user vs. user density

Fig. 6. Impact of scaling the user density on FRS sub-cell capacity

This leads to the following relation between the 2-Hop-Cell capacity and the sub-cell capacities:

$$\frac{1}{C} = \frac{\frac{1}{C_{AP}} + 4\frac{1}{C_{FRS}}}{5}, \tag{10}$$

which means that the resulting capacity of the 2-Hop-Cell can be calculated by re-utilizing the sub-cell capacities for the equal capacity share case as well.

V. Capacity Results

The scenario parameters have been chosen as follows:

- distance between building blocks: 100 m, accordingly the distance between AP and FRS is 200 m
- AP and FRS transmit power: 20 dBm
- Pathloss coefficient: $\gamma = 3$
- FRS receive antenna gain: 0-40 dBi

An interesting property of the cell capacity is visible in Fig. 6(a). When the user density is scaled to very large values, the resulting capacity shows a convergent behavior, which can be explained by the fact that for high user density the area per user is very small and thus, the throughput-distance relation of Fig. 4 is "sampled" very often. The growing number of users is kept in balance by a declining traffic offer per user, as can be seen in Fig. 6. Besides the fact that from Fig. 6(b) the maximum offered traffic per user for a given cell configuration and a given number of users can be determined, it can also be used to determine the maximum number of users that can be served by a given cell configuration and for a given offered traffic per user.

For all following results a user density of $0.01\,{}^{\text{users}}/_{m^2}$ was assumed, which leads to a total number of 2500 users present in the whole 2-Hop-Cell area. In Fig. 7 the resulting capacity of AP sub-cell and FRS sub-cell is evaluated for the case that the whole capacity of the 2-Hop-Cell is concentrated at a single infrastructure element, and the effect of varying the FRS antenna gain is visualized. The capacity of the AP (this case is equivalent to the AP operated as a conventional one-hop BS) amounts to $22.51\,{}^{\text{Mbit}}/_{\text{s}}$. The capacity that can be made available for the relay case, i.e., when the whole capacity of the AP is transferred to the area that is covered by one of the FRSs, amounts, depending on the FRS receive antenna gain, to values between $2.7\,{}^{\text{Mbit}}/_{\text{s}}$ for 0 dBi gain and $15.87\,{}^{\text{Mbit}}/_{\text{s}}$ for 30 dBi gain. The gap between the two curves of Fig. 7 denotes the capacity that is invested into the extension of the coverage area by relaying.

For a FRS receive antenna gain higher than 28 dBi the capacity in the FRS sub-cell does not improve any more, because at this point the highest PHY mode (64QAM${}^3/_4$ $54\,{}^{\text{Mbit}}/_{\text{s}}$) of the regarded Hiperlan/2 physical layer is used without any packet errors and therefore no further rise of throughput on the first hop is possible. Thus, the remaining gap between FRS and AP sub-cell capacity represents a lower bound to the capacity investment into relaying. For the regarded parameter set it amounts to $6.64\,{}^{\text{Mbit}}/_{\text{s}}$.

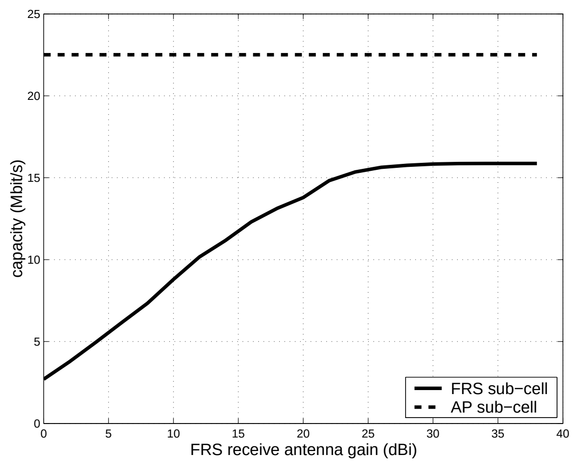
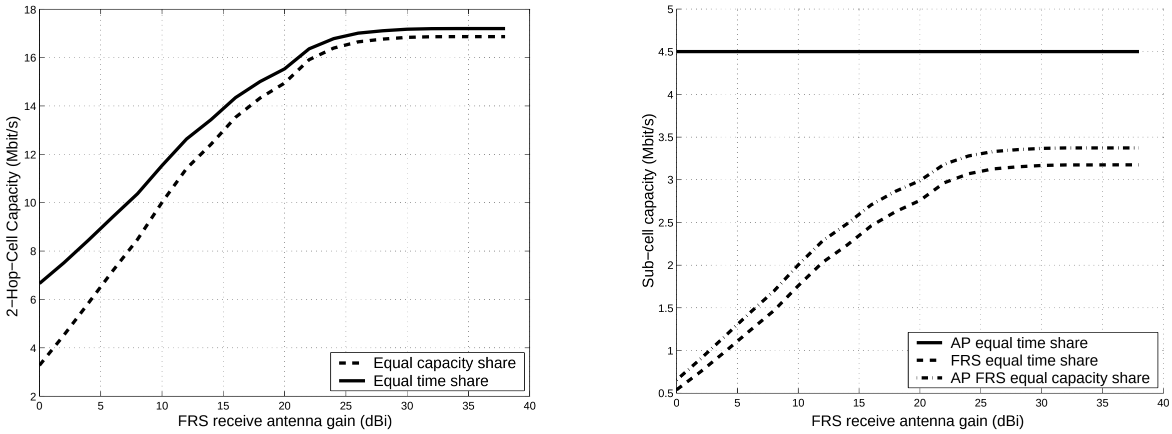


Fig. 7. Capacity of the AP in single-hop mode and capacity of FRS



(a) Capacity in 2-Hop-Cell for equal time share and equal capacity share

(b) Capacity per single infrastructure element for equal time share and equal capacity share

Fig. 8. Resulting 2-Hop-Cell capacity when capacity is distributed to all users of AP and the four FRSs

In Fig. 8(a) the resulting 2-Hop-Cell capacity is visualized, and the two strategies *equal time share* and *equal capacity share* are compared. The users that are served by the AP do not require 2-hop transmission, and therefore many of them are served at a higher end-to end bit rate (see Fig. 3). Therefore, in the equal time share case the AP sub-cell has a higher capacity than the FRS sub-cells; see Fig. 8(b). This is equivalent to the view that a lower fraction of the total cell capacity is transferred to the FRS coverage areas. As this "transmission of capacity by relaying" leads to a capacity loss, transfer of less capacity leads to a lower amount of capacity that is spent on the first hop. This is the reason why the 2-Hop-Cell capacity in the equal time share case is higher than in the equal capacity share case (see Fig. 8(a)).

Fig. 8(b) shows the resulting capacity *per infrastructure element* for the two sharing strategies. In case of equal time share the AP offers a constant capacity share, while the FRSs offer a lower and variable capacity share. Concerning capacity per MP, in the trivial case of equal capacity share it is interesting to note that the FRS receive antenna gain does influence the capacity of *both* AP and FRS, while for equal time share only the capacity per FRS is changed by antenna gain variation.

VI. Conclusion

We have presented a simple but effective method to calculate the traffic capacity of cellular systems that use link adaptation. The method is applicable to both, one-hop and 2-hop cell architectures. Furthermore, the method easily can be extended to cell architectures with three or more hops. To apply this method, a known relation between throughput and distance for a given scenario, and a known spatial distribution of users in the scenario are required.

Our 2-Hop-Cell capacity figures have been obtained by defining two strategies to organize the distribution of AP capacity to the sub-cells of the 2-Hop-Cell. Equal capacity share leads to perfectly fair service availability among all users of the cell, but has the disadvantage of a higher capacity loss compared to equal time share. Equal time share leads to a higher total capacity, because more capacity is kept available at the AP and therefore less capacity is lost on the relaying hop. The trade-off is that there is a difference in service quality between AP and FWR coverage areas.

It is important to note that both sharing schemes do not consider timeslot re-use (i.e., parallel transmission) in spatially independent FRS sub-cells.. In [10] has been shown that even for relatively simple timeslot re-use schemes that employ parallel transmission in two sub-cells at the same time the 2-Hop-Cell capacity can be significantly higher than the capacity of a conventional one-hop architecture.

Relaying allows to transfer a part of the AP capacity from its original coverage area to the FRS coverage area, which can be used to reach an improved coverage and resource utilization. Our method allows to quantify the fraction of the access point capacity that has to be invested for relaying.

In our example scenario the capacity investment for transferring the whole AP capacity to a relaying sub-cell amounts to a minimum of 6.64 Mbit/s for FRS receive antenna gain of 28 dBi or higher. The maximum capacity of the whole 2-Hop-Cell was calculated to 17.2 Mbit/s for the equal time share case, and 16.87 Mbit/s for the equal capacity share case. Compared to the capacity of 22.51 Mbit/s that would be available if the same area would be covered with a conventional 1 hop architecture, we conclude that the capacity of the 2-Hop-Cell is sufficient for many predicted future usage scenarios, especially if the expected significant cost advantage is considered.

Using the methodology described above it is also possible to determine the maximum offered traffic that can be carried by a given cell configuration and for a certain user density, and, for a given user density to evaluate the maximum offered traffic per user, respectively. The results in Fig. 6(a) and Fig. 6(b) are indication for that.

References

[1] B. Walke, "The Wireless Media System - a Candidate Next Generation System," in *Proc. 5th WWRF Workshop*, Phoenix, Arizona, USA, March 2002.

[2] B. Walke, R. Pabst, and D. Schultz, "A Mobile Broadband System based on Fixed Wireless Routers," in *Proc. IEEE Int. Conf. on Communication Technology (ICCT'03)*, Bejing, PR China, Apr. 2003.

[3] W. Mohr, R. Lüder, and K.-H. Möhrmann, "Data rate estimates, range calculations and spectrum demand for new elements of systems beyond IMT-2000 ," in *Proc. of WPMC'02*, Honolulu, Hawaii, October 2002.

[4] B. Walke, "On the Importance of WLANs for 3G Cellular Radio to Become a Success," in *Proc. 10th Aachen Symposium on Signal Theory - Mobile Communications*, September 2001, pp. 13–24.

[5] B. Walke, N. Esseling, J. Habetha, A. Hettich, A. Kadelka, S. Mangold, J. Peetz, and U. Vornefeld, "IP over Wireless Mobile ATM - Guaranteed Wireless QoS by HiperLAN/2," *Proceedings of the IEEE*, vol. 89, pp. 21–40, January 2001.

[6] J. Khun-Jush, P. Schramm, U. Wachsmann, and F. Wenger, "Structure and Performance of the Hiperlan/2 Physical Layer," in *Proc. 50th IEEE Vehicular Technology Conf. (VTC-Fall'99)*, Amsterdam, The Netherlands, Sept. 1999, pp. 2667–2671.

[7] H. Yanikomeroglu, "Fixed and Mobile Relaying Technologies for Cellular Networks," in *Proc. IEEE Workshop on Applications and Services in Wireless Networks (ASWN'02)*, Paris, France, July 2002, pp. 75–81.

[8] P. Gupta and P. Kumar, "The Capacity of Wireless Networks," *IEEE Trans. Inform. Theory*, vol. 46, no. 2, pp. 388–404, Mar. 2000.

[9] ETSI/3GPP, "TR 101 112, Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS (UMTS 30.03)," Tech. Rep., Apr. 1998.

[10] D. Schultz, R. Pabst, and T. Irnich, "Multi-hop based Radio Network Deployment for efficient Broadband Radio Coverage," in *Proc. Int. Symp. on Wireless Personal Multimedia Comm. (WPMC'03)*, Yokosuka, Japan, Oct. 2003.

[11] B. Walke, *Mobile Radio Networks - Networking, Protocols and Traffic Performance*, 2nd ed. John Wiley & Sons, 2002.