Costs and Performance of Non-Cooperative Relay Networks

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Abstract—**Two promising types of networks exist for future wireless cellular networks. The first one is a conventional network (CNT) in which a subscriber station (SS) is directly connected to a base station (BS). The other one is a relay network (RNT). In the considered RNT, a SS is directly connected to a BS or connected to a BS by using a relay station (RS). In this paper, different layouts of a RNT are compared with a CNT in an urban scenario modeled by a Manhattan grid. Two protocols are considered in the RNT, namely a non-cooperative amplify-and-forward and a non-cooperative decode-and-forward protocol. The comparison is based on a physical layer taken from IEEE 802.16 standard. Each network is analyzed separately in the same service area. The bits per second which can be transmitted per cost unit in the considered service area are determined for each type of network. The networks are compared by a cost model introduced in this paper. The costs of a RS are assumed to be a fraction of the costs of a BS. The maximum costs of a RS in relation to the costs of a BS are determined for which a RNT is more cost-efficient than a CNT. It is shown that, depending on the layout of the RNT, a RS may cost up to 6% of the costs of a BS.**

I. INTRODUCTION

Future wireless cellular networks shall provide a high capacity in a given service area especially in urban environments. High data rates shall be offered to a subscriber station (SS) also at the cell border. Frequency bands used by future networks are located at higher carrier frequencies than frequencies of nowadays wireless cellular networks. The coverage of a transmitter is reduced at higher carrier frequencies. Providing high data rates is rather difficult at the cell border of large cells.

Two promising types of wireless cellular networks exist. The first one is a conventional network (CNT) in which a SS is directly connected to a base station (BS). A high capacity can be offered by a large number of BSs per area. However, an increased number of BSs increases the costs of a future network. The second promising type of a future network is a relay network (RNT) as described, e.g., in [1]. Beside BSs and SSs, relay stations (RS) exist in a RNT. A RS forwards messages between a source and destination. Throughout this paper, a RS is assumed to be fix and part of the infrastructure. Limiting the number of hops of a connection to two, two types of connections are established in a RNT called single hop and two hop connections. Using a single hop connection, a SS is directly connected to a BS. A two hop connection is defined as a connection of a SS to a RS which is connected to a BS. A SS at the cell border is enabled to use a two hop connection with a bandwidth efficient modulation and coding schemes because the path loss is reduced compared to a single hop connection. Especially in shadowed areas, a two hop connection may yield a higher throughput between a BS and a SS than a single hop connection [2].

Two non-cooperative relaying protocols are considered in this paper. The protocols are called amplify-and-forward (A&F) protocol and decode-and-forward (D&F) protocol. In the A&F protocol, a RS acts as an analogue repeater. In the D&F protocol, error control coding is applied to the noisy signal at the RS and an estimate of the originally transmitted signal is forwarded. The considered protocols are non-cooperative, i.e., a sink does not receive a signal which is cooperatively transmitted by a source and RSs.

If a CNT or a RNT is preferable depends on which type of network is more cost-efficient. A basic approach of a cost comparison between a CNT and a RNT is given in [1]. In [3], a comparison of a CNT and a RNT is presented assuming hexagonal cells. The applied cost model is based on the assumption that a CNT and RNT offer the same system capacity per area which is achieved by adapting the density of BSs and RSs, respectively. Data rates are estimated by applying Shannon capacity formula.

In this paper, both types of networks are compared by a cost model in an urban scenario. Because of a limited number of positions where a BS or RS can be placed in an urban scenario, it is assumed that the size of a cell can not be planned to achieve an arbitrary system capacity per area. Therefore, different types of networks offer a different system capacity. A cost model for comparing both types of networks is introduced in this paper taking into account that the considered networks vary in the offered system capacity per area. The differences of the offered system capacity per service area are taken into account in the presented comparison by normalizing the system capacity of a network by the costs of the infrastructure. Thus, the bits per second (bps) are calculated which can be transmitted per cost unit, e.g. in €. While the costs of the CNT are coupled with the costs of a BS, the costs of a RNT depend on the costs of a BS and a RS. The bits per second

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and per cost unit of a RNT and a CNT are compared. As proposed in [3], the maximum relative costs of a RS related to a BS are determined for which a RNT is more cost-efficient than a CNT. Precondition of a comparison of a CNT and RNT is that both types of networks use comparable resource management algorithms and that both types of networks have a density of BSs which offers at least a required system capacity in the predefined service area.

The urban scenario considered in this paper is modeled by a Manhattan grid [4]. Each network is analyzed separately in the same scenario. A PHY-layer of IEEE 802.16 [5][6] is applied in both types of networks motivated by the current discussion about relaying in IEEE 802.16 [7][8]. Four layouts of a RNT differing in antenna configuration and protocols are analyzed and compared with a CNT.

This paper is organized as follows. In Section II, the scenario is described in which a network is deployed. The CNT and RNT are presented including the applied resource allocation which mainly affects the results of the comparison of the networks. The model used for the network comparison is given in Section III. Section IV describes how the networks operate. A comparable assignment strategy of the SSs to the BSs and RSs, respectively, is presented for the CNT and RNT followed by the description of the physical layer taken from IEEE 802.16 [5][6]. Section V shows how the performance of the CNT and RNT is estimated based on system level simulations and presents the results of the network comparison. Conclusions are drawn in Section VI.

II. NETWORK STRUCTURE

A. *Scenario*

Each network operates in an urban scenario with a high demand of traffic per area. The urban environment is modeled by a Manhattan grid [4], which consists of rectangular streets separated by blocks. Mobile SSs are only moving along the streets and are not inside of a block. The SSs are uniformly distributed in the streets. A line of sight (LOS) connection between two stations is assumed if both stations are in the same street.

The deployments of both types of networks are chosen such that each one fulfills at least a required system capacity per service area. Each type of network operates in FDD mode and only the downlink is considered. A TDMA frame based transmission using OFDM is applied in the downlink according to IEEE 802.16 [5][6]. The smallest resource unit carrying traffic of a SS is a slot which is equivalent to a single OFDM symbol.

B. *CNT*

In this section, the structure of the CNT is described. An extract of the deployment of the CNT is given Fig.1 where BSs are depicted by blue dots. The deployment of the CNT is chosen such that a SS has always LOS to at least one BS. BSs are placed on the street crossings and are placed in a regular pattern in order to use a number of BS which is as small as possible. The system capacity can be increased by choosing a smaller distance between the BSs. The BSs are equipped with an omni directional antenna. The coverage of a BS is only considered in the streets. Note that a cell is not represented by a hexagon in the Manhattan Grid.

A round robin scheduling algorithm [9] fairly allocates the slots of a frame to SSs in a cell. As a traffic model, a full buffer model is taken. A reuse factor of $r = 2$ is used. The system bandwidth is split into two frequency bands to avoid strong co-channel interference. By the reuse factor $r = 2$, co-channel interference is reduced in the major part of a cell except street crossings where SSs suffer from co-channel interference. A reuse factor of $r = 1$ leads to a low system capacity of the CNT because of strong co-channel interference. A reuse factor of $r > 2$ would reduce the co-channel interference, especially at the street crossings, but would decrease the available bandwidth in a cell leading to a low system capacity of the CNT. Therefore, $r = 2$ is assumed for the CNT in all following considerations. To mitigate the problem of high interference at street crossings for $r = 2$, coordination across the cells is assumed. The coordination demands that transmission of OFDM symbols is synchronous in all cells. If a SS has a signal to interference-plus-noise ratio (SINR) which inhibits an establishment or maintenance of a connection, the BS which is the strongest interferer will stop its downlink transmission during the reception of the SS. Especially, the small amount of SSs located at the street crossings benefits from coordination. Because of the considered round robin scheduling algorithm, the system capacity is not affected significantly by the coordination, but the coordination ensures that no SS is unable to establish a connection because of a permanently too low SINR.

C. *RNT*

The deployment, the applied relaying protocols and the resource allocation of the considered RNT are described in the following.

An extract of the deployment of the RNT is given in Fig.2. BSs are represented by blue dots and RSs are depicted by red diamonds. A BS is placed in the centre of a cell and supports four RSs in a RNT. The distance between a BS and its RS is chosen such that a bandwidth efficient modulation and coding scheme (MCS) taken from IEEE 802.16 is enabled. In all streets, a SS has a LOS to a RS or BS.

Two relaying protocols are analyzed. Applying the A&F protocol in downlink direction, a noisy signal is received by a RS from the BS. The signal is amplified so that a scaled version of the noisy signal is forwarded to a SS. If the D&F protocol is used, a noisy signal is received by a RS, the signal is decoded at the RS and an estimate of the originally encoded, transmitted signal is forwarded to the SS**.** The MCS used on the first hop of a two hop connection is always the same as on the second hop. The decision if the

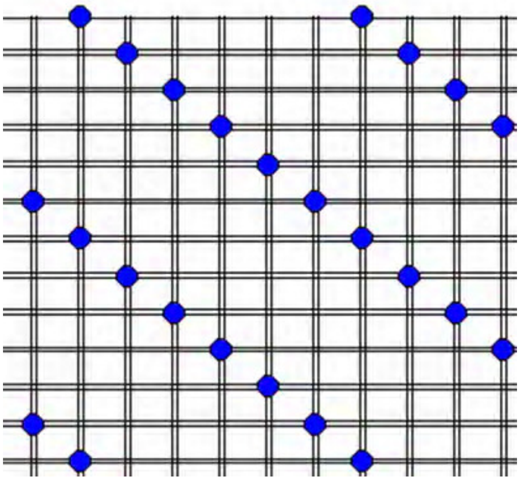


Fig. 1. Deployment of a CNT with a distance of six blocks between neighbored BSs in the same street.

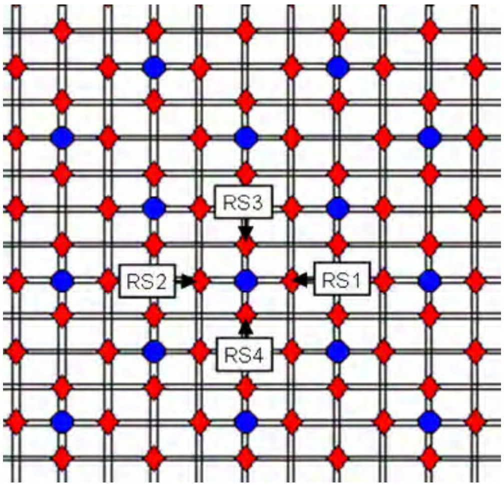


Fig. 2. Deployment of the RNT. BSs are depicted by blue dots. A cell contains a BS and four RSs depicted by red diamonds. A BS is placed in the centre of the four RSs which are fed by a BS.

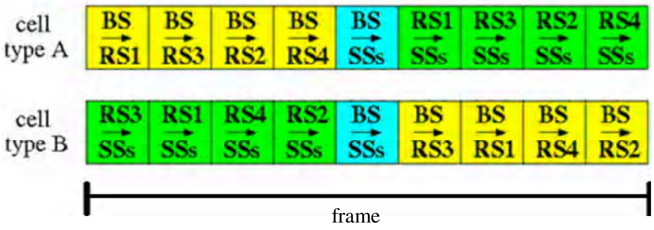
transmission of a block is erroneous is made at the SS in both relaying protocols. Both relaying protocols are chosen because they are not complex. Note that the system capacity of a RNT can be increased, e.g., by adapting the MCS to each hop of a two hop connection.

Since the RS are fixed stations and part of the infrastructure, the link between BS and RS can be improved by a directive antenna. If directive antennas are assumed, four directive antennas are installed at the BS and directed to the four RSs in a cell. Four different layouts of the RNT are considered in the rest of this paper. The A&F protocol is analyzed where the BS is firstly equipped with an omni directional antenna (A&F, omni) and secondly with an omni directional antenna for the BS-to-SS link and with directive antennas for the four BS-to-RS link (A&F, direc). The D&F protocol is also applied using an omni directional antenna (D&F, omni) and directive antennas (D&F, direc) at a BS. The use of directive antennas improves the signal power on the BS-to-RS link which leads to an improved SINR on this link.

The BSs of a RNT exchange information such that the use of radio resources in adjacent cells is coordinated which reduces co-channel interference. Coordination across cells is applied such that the start and end of a frame is synchronous in each cell. Co-channel interference is reduced by a non-adaptive resource allocation scheme without intra-cell reuse [11]. The resources are shared between the BS and RSs of a cell by using a frame structure given in Fig.3. Two types of cells are defined called cell type A and cell type B where both use the full system bandwidth. The cells are arranged over the Manhattan grid in form of a checker. The frame consists of $2N_{RS,cell}+1$ subframes which are of fixed length. Subframes are ordered such that co-channel interference is minimized. As depicted in the cell in the centre of Fig. 2, RS1 is the RS in the east of a BS, RS2 in the west, RS3 in the north and RS4 in the south. In cell type A, the $N_{RS,cell}$ subframes of the BS-to-RS links are transmitted first followed by the BS-to-SS subframe. The $N_{RS,cell}$ RS-to-SS subframes follow in the same order as the RSs received from the BS. In cells of type B, the subframe order starts with the subframes of transmitting RSs. The BS-to-SS subframe is in the middle followed by the BS-to-RS subframes. The order of the BS-to-SS and RS-to-SS subframes is chosen in both types of cells such that a RS of cell A only transmits/receives while a RS which has a NLOS to the active RS of cell A receives/transmits in cell B. For instance, RS1 receives in the east of cell type A, while RS3 is transmitting in the north of a neighboring cell of type B.

Because of the repetition character of the relaying protocols, a BS-to-RS subframe consists of as many slots as a RS-to-SS subframe. Taking into account that the SSs are uniformly distributed on the streets, the length of a BS-to-SS and a RS-to-SS subframe is set to the fraction of SSs which is expected to be assigned to a BS/RS of a cell on average. The slots of a subframe are allocated by a round robin scheduling algorithm to the SS assigned to a BS and RS, respectively. Thus, the resources are fairly shared among the SSs of a cell.

The frame structure is adapted to the applied relaying protocols. A frame structure which is proper for relaying protocols applying different MCSs on different hops of a two hop connection is proposed in [2].



cell type A	BS → RS1	BS → RS3	BS → RS2	BS → RS4	BS → SSs	RS1 → SSs	RS3 → SSs	RS2 → SSs	RS4 → SSs
cell type B	RS3 → SSs	RS1 → SSs	RS4 → SSs	RS2 → SSs	BS → SSs	BS → RS3	BS → RS1	BS → RS4	BS → RS2

Fig. 3. Frame structure for cell type A and B for non-adaptive resource allocation without intra-cell reuse.

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III. MODEL FOR NETWORK COMPARISON

In the following, the cost model used for a network comparison of CNT and RNT is given. Each network operates in the same service area and in each network the resources are fairly shared among the SSs. It is assumed that each BS and RS transmits with the same power and each network uses the same system bandwidth. Because two stations of a cell never transmit simultaneously, the same energy is applied in a CNT and RNT per cell. Both types of networks shall achieve at least a system capacity C_{target}. A minimum number of BSs in each network shall be chosen to achieve C_{target} in the service area. Let the index $i = c$ indicate the CNT and $i = r$ the RNT and N_i the number of BS in a CNT and RNT, respectively. The system capacity which is offered by a network $C_{sys,i}$ is defined as

$$C_{sys,i} = N_i \ \mathrm{E}\{T_{cell,i}\} \tag{1}$$

where $\mathrm{E}\{\cdot\}$ denotes the expectation value and $T_{cell,i}$ the cell throughput. Each network fulfills

$$C_{sys,i} \geq C_{target} \, . \tag{2}$$

Networks are compared by a cost model in which the bits per second (bps) per cost unit are calculated. The costs of a BS of a CNT are defined as K_{BS}. The costs of a BS of a RNT are assumed to be the same as in the CNT. The additional costs of a RNT are summed up in the costs of a RS represented by K_{RS}. These costs are:

- the costs of a RS itself, e.g., costs of hardware and rent of a site for a finite duration,
- the costs which are generated at a BS by a RS, e.g., costs of additional directive antenna.

Assuming that K_{RS} is smaller than K_{BS}, K_{RS} is a fraction of K_{BS}:

$$K_{RS} = \alpha \cdot K_{BS} \tag{3}$$

with $\alpha \in [0;1[$ as the relative costs of a RS.

The different networks do not have exactly the same system capacity. The system capacity per service area depends on the cell size. Because BSs are always placed on street crossings, only a limited number of cell sizes exist. Hence, only a limited number of system capacities exists in the considered service area. Deployments of different types of networks offering the same system capacities can not be found. To determine the system capacity per cost unit, the system capacity is normalized by the number of infrastructure elements times the costs of a BS and RS, respectively. The bps per cost unit in the CNT is given by

$$\Omega_c = \frac{C_{sys,c}}{N_c K_{BS}} = \frac{\mathrm{E}\{T_{cell,c}\}}{K_{BS}} \, . \tag{4}$$

Denoting the total number of RSs in the RNT by N_{RS}, the bps per cost unit in the RNT is given by

$$\Omega_r(\alpha) = \frac{C_{sys,r}}{N_r K_{BS} + N_{RS} \alpha K_{BS}} = \frac{\mathrm{E}\{T_{cell,r}\}}{K_{BS}(1 + \alpha \frac{N_{RS}}{N_r})} \tag{5}$$

where Ω_c and Ω_r are given in bps/€. Let $\alpha_{\max}$ be the maximum costs of a RS for which a RNT is more cost-efficient than a CNT. Applying

$$\Omega_r(\alpha_{\max}) = \Omega_c \tag{6}$$

yields

$$\alpha_{\max} = \left(\frac{\mathrm{E}\{T_{cell,r}\}}{\mathrm{E}\{T_{cell,c}\}} - 1 \right) \frac{N_r}{N_{RS}} \, . \tag{7}$$

If the relative costs α of a RS are equal or smaller than $\alpha_{\max}$, a RNT is preferable.

IV. NETWORK OPERATION

A. *Assignment of SS to BS or RS*

The performance of a network in terms of system capacity depends on how a SS is assigned to a BS or RS. The assignment strategy must be equivalent in the CNT and RNT in order to enable a fair comparison by applying the cost model. For instance, choosing the BS giving the highest receive power to a SS in the CNT and choosing the BS or RS enabling the highest throughput in the RNT would lead to an unfair comparison. In the following, SSs are assigned by a best server strategy, i.e., a SS is assigned to a BS and RS, respectively, concerning the receive power. This assignment strategy is not optimal in terms of user throughputs, but enables a fair comparison of both types of networks. In the CNT, a SS measures the receive power $P_{SS,n}$ of a signal transmitted by a BS n, where $1 \leq n \leq N_c$. The SS is assigned to the BS for which

$$n_{\max} = \arg\max_n \left(P_{SS,n} \right) \tag{8}$$

holds.

In the RNT, a SS is assigned to a BS or RS. A SS which is directly assigned to a BS uses a single hop connection and a SS which is assigned to a RS uses a two hop connection. The best serving BS or RS is chosen as follows. First, the best one hop connection is calculated by determining the best serving BS using (8) but $1 \leq n \leq N_r$ holds in the RNT. Next, the best two hop connection is determined. The quality of a two hop connection depends on the receive

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power $P_{RS,m}$ of the first hop at a RS and the receive power $P_{SS,m}$ of the second hop at a SS where $1 \le m \le N_{RS}$. The best two hop connection is given by

$$m_{\max} = \arg\max_{m}\left(\min\left(P_{RS,m}, P_{SS,m}\right)\right). \tag{9}$$

A RS is assigned uniquely to a single BS according to the deployment of the RNT. Therefore, if a RS is chosen by the SS, the BS is set, too. The decision that a SS takes the two hop connection instead of the single hop connections is made if

$$\min\left(P_{RS,m_{\max}}, P_{SS,m_{\max}}\right) > P_{SS,n_{\max}}. \tag{10}$$

B. *Physical Layer*

The physical layer of the CNT and RNT is modeled according to the WirelessMAN-OFDM PHY Layer of IEEE 802.16. The OFDM signal consists of 256 subcarriers. 192 subcarriers carry data. The other subcarriers serve as pilot, guard and null subcarrier. Seven MCSs are considered using BPSK, QPSK, 16-QAM and 64-QAM and a concatenated Reed-Solomon and convolutional code of code rate 1/2, 2/3 or 3/4. The MCS of a connection is chosen by a link adaptation algorithm which adapts the MCS of each connection once per frame. Perfect channel state information is assumed at the BS. A MCS of a BS-to-SS connection is adapted by taking into account the SINR at the SS. The link adaptation algorithm used for a SS assigned to a RS is different for the A&F and D&F protocol. Applying the A&F protocol, the adaptation depends on the SINR which is the ratio of the signal power received by the SS and the interference plus noise power which is added to the signal power at the RS and SS. Applying the D&F protocol, the minimum of the SINR values of the channel between BS and RS and the channel between RS and SS determines the MCS.

A frame transmitted in the CNT is introduced by a preamble having a length of two OFDM symbols and by a frame control header having a length of one OFDM symbol. A frame structure and signaling capable of relaying is not included in IEEE 802.16 yet. Obviously, the use of RS demands an increased signaling between BS, RS and SS in comparison to a CNT. The increased signaling is modeled by two additional OFDM symbols per RS and per frame where one OFDM symbol is assumed as a shorten preamble and the other symbol as control information. Taking into account a preamble transmitted by the BS and a frame control header, eleven OFDM symbols per frame are assumed to carry signaling in the RNT.

V. PERFORMANCE EVALUATION

A. *Estimation Method for statistics of cell throughput*

The performances of the different networks are estimated by simulations concerning the following assumptions. A Manhattan grid with 36x36 blocks is simulated using a wrap around technique. The blocks of buildings have a length of 200m. The street width is 30m. The same service area is covered by 162 BSs in the RNT and by 216 BSs in the CNT. Channel models defined for a Manhattan like environment are taken from [12] including path loss, slow, and fast fading. A carrier frequency of 5 GHz is assumed. The transmit power of the BSs and RSs is 35dBm. An antenna gain of 17 dBi and a front-to-back ratio of 23 dB is chosen in layouts of the RNT in which a BS is equipped with directive antennas. RS and SS are equipped with omni directional antennas. The system bandwidth is 7 MHz. In the CNT, the system bandwidth is split into two frequency bands because of the applied frequency reuse of $r = 2$. An additive white Gaussian noise is considered at a receiver having a power of -98 dBm assuming a bandwidth of 7 MHz and -101 dBm assuming a bandwidth of 3.5 MHz [13]. The frame duration is 10ms. The duration of the guard interval is 4 µs leading to 147 OFDM symbols in a frame of transmitted in the CNT and 277 OFDM symbols in a frame of the RNT. A number of SSs is chosen such that the probability that no SS is assigned to a BS or RS can be neglected. A SS moves with 2.78 m/s. The networks achieve at least $C_{target} = 1300$ Mbps which is equivalent to system capacity per area covered with streets of 19 Mbps/km^2.

A statistic of the cell throughput is gathered from system level simulations. Link level performance in terms of OFDM symbol error rate is taken from [14]. Link error prediction is based on a link-to-system level interface given in [15]. The RNT is simulated by an implementation of the non-adaptive resource allocation. The CNT is simulated by a simplified model which reduces the complexity of the estimation of the cell throughput. Neglecting fast fading effects, a SINR threshold of 3.5 dB is presumed for a successful connection establishment using the most robust MCS. In the CNT, a fraction of β % of SSs exists on average per cell which does not exceed this threshold. These β % of SSs are located at or near the street crossings and are assumed to depend on coordination across cells to establish a connection. Using coordination across cell, only 100%-β=94.7% of the resources of a cell are occupied on average because of the applied full buffer model and fair resource scheduling. Taking into account the coordination across cells, the β % of SSs have a similar interference situation in comparison to SSs being not at street crossing. Instead of simulating all SS, only SS having an on average sufficient SINR are simulated which leads to a resource utilization of 100% and a optimistic system capacity $C_{c,opt}$. The actual estimate of C_c is given by

$$C_c = \frac{100-\beta}{100} C_{c,opt}. \tag{11}$$

B. *Performance of the Networks*

In this section, the simulations results are presented. The cumulative density function (CDF) of cell throughput T_{cell} is given for the CNT and for the four layouts of the RNT in Fig. 4. The CDF of the CNT is the result of the simplified model in which 100% of the resources are allocated to SS, but SSs with an SINR smaller than 3.5 dB averaged over the statistics of the fast fading are not considered in the resource allocation. Thus, the CDF of the CNT represents the optimistic estimate $C_{c,opt}$ of the statistics of the cell throughput. Due to the reuse of $r = 2$, the CNT has a lower cell throughput than the layouts of the RNTs for which $r = 1$ is assumed. The CDFs of the RNTs using the D&F and A&F protocols show that the D&F protocol is superior to A&F in sense of cell throughput. The cell throughput is increased in the RNT by the use of directive antennas on the BS-to-RS link compared to layouts in which only omni directional antennas are used. By the use of directive antennas, the probability of applying the most bandwidth efficient MCS is increased for a two hop connection.

Results of the comparison are summarized in Table I. Simulation results of the CNT show that β =5.3% of the SS have an averaged SINR smaller than 3.5 dB. Using equation (11), the cell capacity of the CNT is 7.5 Mbps. The maximum cell capacity is 9.3 Mbps achieved by the RNT applying the D&F protocol and using directive antennas. Assuming that the RNT is more cost-efficient than the CNT, the relative costs α_{max} of a RS applying the A&F protocol is maximum 2.0 % if only an omni directional antenna is used at the BS and 4.0% if additionally four directive antennas are used. The use of directive antennas leads to a trade-off. On the one hand the use of directive antennas allows higher costs, on the other hand directive antennas increase the complexity of the hardware which must be paid. RSs applying the D&F protocol yield a higher cell capacity which leads to increased maximum relative costs α_{max} of a RS compared to RS applying the A&F protocol. The maximum relative costs α_{max} of a RS are enhanced to 5 % using only an omni directional antenna and 6% using additionally four directive antennas at the BS.

The costs of a RS are allowed to be only a fraction of the costs of a BS, but the complexity of a RS is smaller than the complexity of a BS. An implementation of higher layer protocols is not necessary at the RS leading to a reduced computational complexity requirement and a reduced consumption of electricity. Furthermore, a RS does not require an access to backbone service as it is needed at the BS.

The presented results of the maximum relative costs α_{max} of a RS are developed in an urban scenario. The urban scenario in which a SS is always assigned to a BS or RS with a LOS and the network structure of the RNTs are chosen because they are pessimistic for the RNTs for three reasons. First, in a scenario in which a SS may have a non-LOS or a LOS connection to a BS or RS, a SS has a higher probability of having a LOS connection in the RNT because more infrastructure elements exist in the RNT than in the CNT leading to a reduced path loss on average. Second, a SS benefits more from the reduced path loss of a two hop connection compared to a single hop connection in a scenario in which a SS has a non-LOS connection to a BS or RS, especially, if a LOS connection between BS and RS can be ensured. Third, the efficiency of the RNT can further be improved by applying more sophisticated relaying protocols. For instance, the system capacity of a RNT can be increased by adapting the MCS to each hop of a two hop connection separately or the system capacity of a RNT is increased by cooperative protocols where the BS and RS cooperate in downlink [16]. Because of these three reasons, the maximum relative costs α_{max} are expected to be larger in further case studies of RNTs.

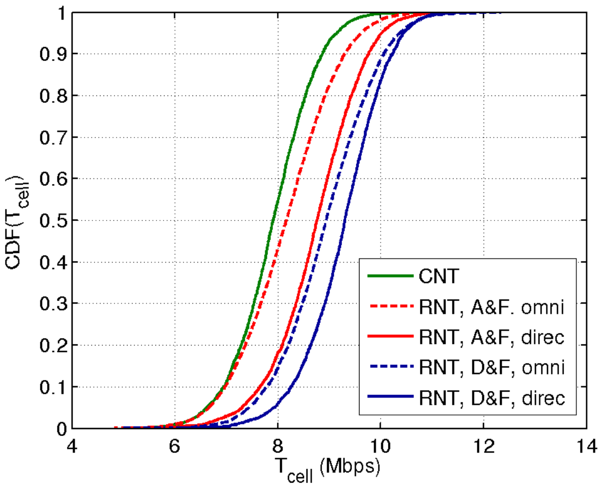

Fig.4. CDF of cell throughput in a CNT and different RNTs.

TABLE I
COST COMPARISON

Para-meter	CNT., r=2	A&F, omni	A&F, direc	D&F, omni	D&F, direc
$E\{C_{cell}\}$	7.5 Mbps	8.1 Mbps	8.7 Mbps	9.0 Mbps	9.3 Mbps
α_{max}	/	2.0%	4.0%	5.0%	6.0%

VI. CONCLUSION

This paper presents a cost model for a fair comparison between a CNT and a RNT applying non-cooperative relaying protocols. This cost model can be applied to various scenarios.

Assuming an urban scenario in which a high coverage is ensured, performance evaluations of four layouts of a RNT show that the D&F protocol yields a higher system capacity than the A&F protocol. The system capacity is further improved by directive antennas on the link between BS and RS. The maximal costs of relaying making a RNT more

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cost-efficient than a CNT are determined for the layouts of the RNT in an urban scenario. A RS applying the D&F protocol may cost more than a RS applying the A&F protocol. The use of directive antennas between BS and RSs allows higher costs of the RS.

The costs of a RS are allowed to be a fraction of the costs of a BS to make a RNT more cost-efficient than a CNT. The performance evaluation shows that the maximum relative costs of a RS related to the costs of a BS are between 2.0 % and 6.0% depending on the applied layout of the RNT.

Cooperative relaying protocols are not considered in this paper. Since cooperative relaying protocols promise efficient bandwidth utilization, an approach to compare a CNT with a RNT applying a cooperative relaying protocol is interesting for future work.

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