Performance Analysis of the Subframe Concept in the IEEE 802.16 Network

Karsten Klagges
RWTH Aachen University
Communication Networks
Aachen, Germany
Email: kks@comnets.rwth-aachen.de

Christian Hoymann
RWTH Aachen University
Communication Networks
Aachen, Germany
Email: hoy@comnets.rwth-aachen.de

***Abstract*— A new concept to enable relay support in the Institute of Electrical and Electronics Engineers (IEEE) 802.16 Standard has been presented in [1]. The proposed concept introduces a nested Multi-hop Subframe, that is allocated by the Base Station (BS). The Relay Station (RS) takes over the control of the subframe and builds a 802.16 compliant Medium Access Control (MAC) frame within the allocated period. This paper presents performance analysis of the proposed concept, that have been acquired by the IEEE 802.16 implementation in the Wireless Network Simulator (WNS) [2].**

I. Introduction

Recent research in the area of relay enhanced IEEE 802.16 network has evolved a concept to embed nested subframes in the Point to Multi Point (PMP) MAC Frame.

The IEEE 802.16 mesh mode is an optional feature of the standard to route traffic directly between Subscriber Stations (SSs) like the HiperLAN/2 (H/2) direct mode [3]. The mesh mode replaces the PMP frame structure [4]. Thus, legacy 802.16 stations are not able to communicate with such a mesh network.

The Task Group IEEE 802.16j wants to overcome these limitations. It aims to specify enhancements for multi-hop operation without further modifications to SSs. Hence, the frame structure shall be PMP compatible and the MAC management procedures, such as handover or association, shall not be modified. Unlike the 802.16 mesh mode the task group aims at tree-based deployment only.

This paper gives a short introduction into the aim of the Subframe Concept of the IEEE 802.16 network [1]. Section III presents some assumptions about the cellular system in advance. Finally Section IV presents the simulation results that have been acquired with the WNS.

II. Nested Subframe

The Subframe Concept [1] introduces a reserved phase in the Uplink (UL) subframe of the 802.16 MAC frame, which is under the control of the RS. The RS takes over the responsibility to build a complete MAC frame within the reserved phase. This nested subframe contains all necessary information to interpret it as a full 802.16 MAC frame.

This concept also allows the allocation of several subframes for multiple RSs of the cell. Figure 1 shows the extended MAC frame that allocates subframes for two associated RSs. Additionally the figure shows the concurrent allocation of bursts on the first and on the second hop. For a more detail description of the subframe concept see [1].

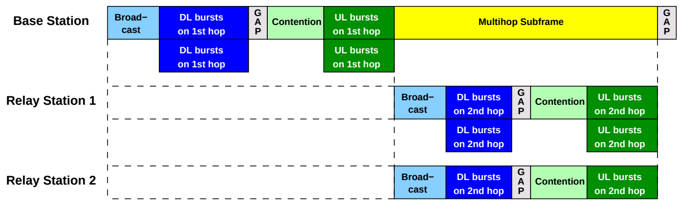
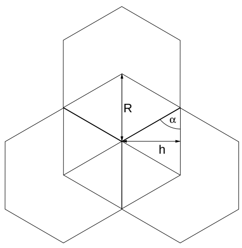


Fig. 1. Nested Subframe with SDMA and SDM

The proposed concept shall be investigated in a cellular environment. Each cell contains three RSs that are placed amid the cell or at the border. In the following the cellular deployment is shown for a coverage extension use case.

Due to the deployment of the RSs on the border of the single hop cell, the cell's shape is a dodecagon as shown below.



As a consequence the deployment of cells differ from single hop networks. For the relay enhanced cell the radius of the inner circle is calculated like in the single hop cell as:

$$h = R\frac{\sqrt{3}}{2} \quad \text{or} \quad h = R\sin 60° \qquad (1)$$

The reuse distance of a 1-hop cell deployment of a cluster with size N is given by

$$D = R\sqrt{3N} \qquad (2)$$

While the reuse distance of a 2-hop cell deployment with 3 relay stations per cell is given by

$$D = 3R\sqrt{N} \qquad (3)$$

Table I shows reuse distance values for cluster order 3, 4, 7 and 12 for single hop cells as well as for relay enhanced cells with 3 RSs derived by Equation 1 and 3.

According to the deployment of the RSs in the cell shown above, the relay enhanced cellular network is shown in Figure 2.

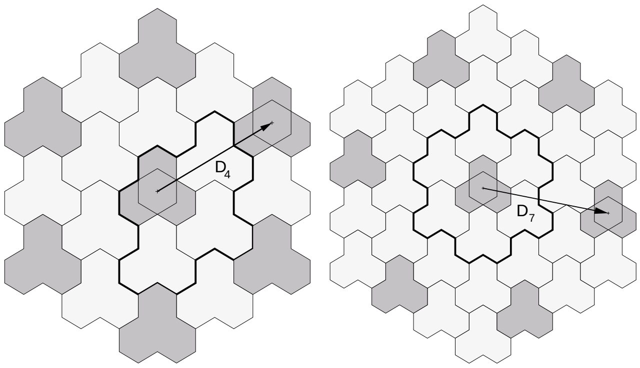
III. Simulation

The Subframe Concept has been implemented in the Wireless Network Simulator (WNS) which is an event driven

Cluster size N	0 RS	3 RS
3	3	$3\sqrt{3} = 5.20$
4	3.46	6
7	4.58	$\sqrt{(\frac{9}{2}\sqrt{3})^2 + (\frac{3}{2})^2} = 7.94$
12	6	$6\sqrt{3} = 10.39$

TABLE I

REUSE DISTANCE D FOR 0 AND 3 RELAY STATIONS PER CELL



(a) Cluster order 4 (b) Cluster order 7

Fig. 2. Relay enhanced cell deployment

system level simulator. The WNS provides a modular component concept that makes protocol implementation easy. For the performance analysis of the Subframe Concept the IEEE 802.16 module has been supplemented.

A. Simulation Base Parameters

It is important that the subframe duration is long enough to carry the offered traffic on the second hop. In the following a rough estimation of the subframe duration ratio will be affiliated.

We assume there are n_{1hop} SSs directly connected to the BS and each RS serves n_{2hop} SSs. Additionally we assume that the RSs can always be merged into one spatial group for transmissions on the first hop. Further, RSs operate in parallel on the second hop which means transmissions in subcells occur simultaneously since RS are not coordinated.

Figure 3 shows a simplified frame layout while k is the grouping order, t_s the slot duration, t_{sf} the subframe duration and t_f the duration of the whole frame. Broadcast phases are left out. Bursts to and from a single SS are shown in light gray. Bursts to and from RSs are shown in dark gray.

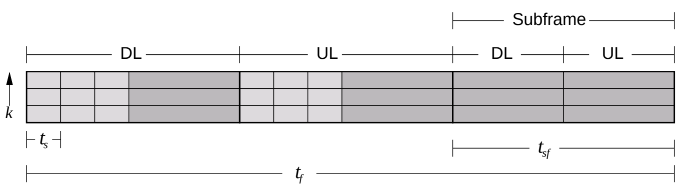


Fig. 3. Frame to Subframe Ratio

The subframe duration ratio can be calculated:

$$r_{sf/f} = \frac{t_{sf}}{t_f} \tag{4}$$

While t_{sf} and t_f can be calculated as:

$$t_{sf} = 2 \cdot n_{2hop} \cdot t_s \quad t_f = 2 \cdot t_s \left(\frac{n_{1hop}}{k} + n_{2hop} \right) + t_{sf} \tag{5}$$

Due to the higher interference level caused by parallel transmissions of the RSs in the cell it is expected, that the Signal to Interference plus Noise Ratio (SINR) decreases on the second hop. Hence a more robust modulation scheme must be chosen. As a result the data rate on the second hop decreases and the subframe duration must be adapted. If we assume, that the data rate decreases by the factor $n = 1.5$ with the next robust modulation and coding scheme the subframe ratio can be calculated as shown in Table II.

Grouping Order k	adapted Subframe Ratio $n \cdot r_{sf/f}$
1	0.375
2	0.3
3	0.27

TABLE II

SUBFRAME RATIO

IV. RESULTS

The developed Subframe Concept for IEEE 802.16 has been evaluated through event driven computer simulations. Relay enhancement can be used to extend the cell coverage or to increase the cell throughput. For both scenarios simulations have been performed.

In the following the application of RS to extend the cell coverage is called *Coverage Scenario* and the application of RS to increase the cell throughput is called *Throughput Scenario*.

Common parameters for both scenarios are listed in Table III.

Parameter	**Value**
Antenna array	Uniform Circular Array
Antenna elements	9
Transmit Power	30 dBm
# cluster	7
Cell size	1000 m
Bandwidth	20 MHz
Pathloss	$28.3 \log(d[m]) + 41.9$
Shadowing	No
Fast fading	No
Mobility	No
Traffic model	symmetric, neg. exp IAT
Packet size	1024 bit
OFDM symbol duration	13.89 μs
Frame length	10ms - 720 OFDM symbols
Data carriers	192
Sub bands	1

TABLE III

SIMULATION BASE PARAMETERS

A. Throughput Scenario

The evaluated scenario consists of seven cells, each with a central base station and three relay stations that are placed amid the cell. The aim of the relay deployment is to serve

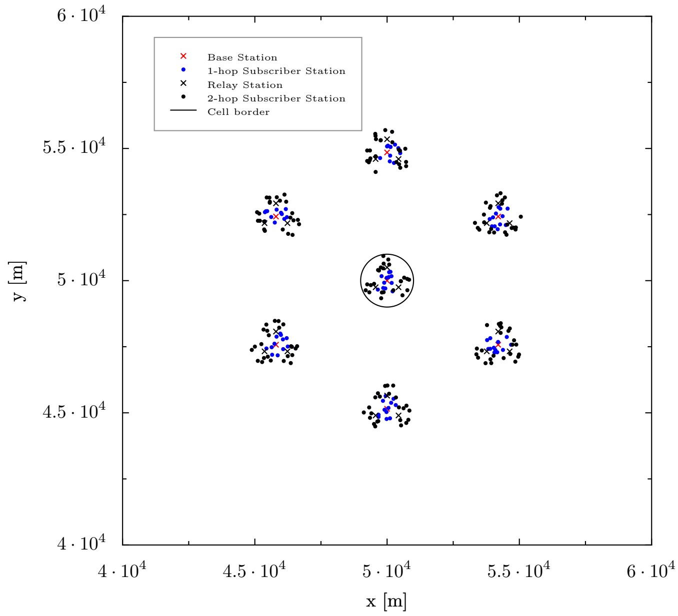


Fig. 4. Position of Stations for Throughput Scenario

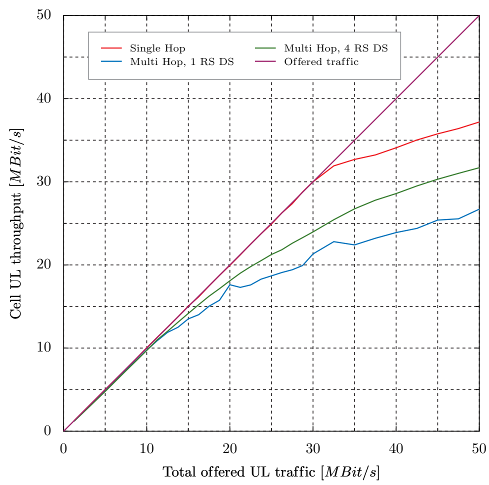


Fig. 5. UL throughput of Throughput Scenario

SSs that are arranged at the border of the cell via RSs. For evaluation, only the inner cell has been considered. The throughput scenario has been evaluated with twelve SS on the first hop and eight SS on the second hop for each relay station.

Additionally a single hop reference simulation has been examined. In this case the SSs that have previously been associated to the RSs are associated to the BS. Hence the subscriber density is equal in both cases.

Figure 4 shows the deployment of cells for the Throughput Scenario. While the azimuthal coordinates of the first hop stations are equally distributed, the radial component is defined by the square distribution. As a result some stations are associated to the base station, even if a relay station is closer to the subscriber than the base station. Due to the symmetry of the cell this does not falsify the results shown later on.

1) Throughput: Figure 5 and Figure 6 show the cell throughput for the single hop reference scenario and through-

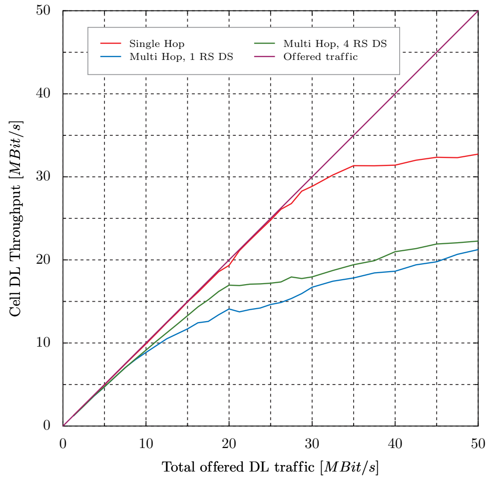


Fig. 6. DL throughput of Throughput Scenario

put graphs for multi hop scenarios with one and four data streams at the RSs. In the single hop scenario the offered traffic is carried until a value of $27.5\,MBit/s$ in downlink and $30\,MBit/s$ in uplink. The maximum throughput is reached at about $33\ MBit/s$ in downlink and not reached in the uplink within the shown offered UL traffic.

The relay enhanced cell carries significantly less throughput. In uplink the overload is reached at about $12.5\ MBit/s$. In downlink even $7.5\ MBit/s$ offered traffic are hardly carried. The difference between one and four data streams at the RSs is fractional. The maximum throughput in the scenario with four data stream lies about $5\ MBit/s$ over the single data stream scenario in UL and about $2\ Mbit/s$ in Downlink (DL).

The remarkable difference in DL and UL throughput arise from the scheduling strategy chosen in the RS. While the *Round Robin* strategy always allocates equal time slots for all SSs in uplink, the *Proportional Fair* strategy tries to prefer low performance SSs. This is done in all RSs simultaneously. Since the low performance SSs are arranged close to the border to the neighbor subcell, the RS directs a beam to the direction of the neighbor subcell. This lowers the SINR beneath the minimum of $6.4\,dB$ which is necessary for a successful transmission.

2) Delay: Delay graphs are shown at a total offered traffic of $20\ MBit/s$. Here the Complementary Cumulative Density Function (CCDF) is shown for uplink and downlink. It is remarkable that the minimum DL delay for the SSs that are served by the relays lies at $15\ ms$. This equals the duration of a full frame plus the duration of first hop subframe. The minimal duration can be explained as follows. For this the journey of a single packet is listed that passes the cell in a best case.

1) The Packet Data Unit (PDU) starts at the base station closely before the beginning of the frame.
2) The PDU is scheduled within the current frame and is transmitted to the relay station.
3) Due to the early scheduling of PDUs at the beginning of the first hop frame, the PDU can not be scheduled within the current frame, because the schedule is already done at the RS. Hence the RS schedules the PDU within

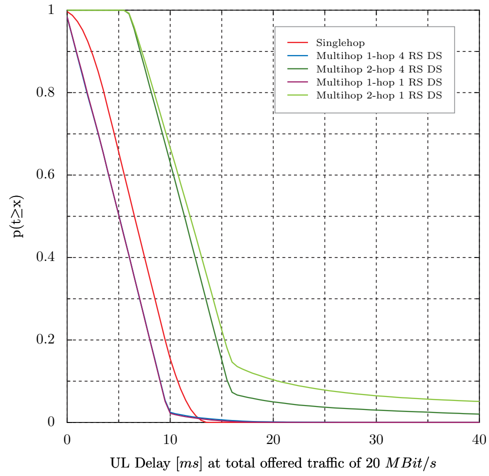


Fig. 7. UL delay of Throughput Scenario

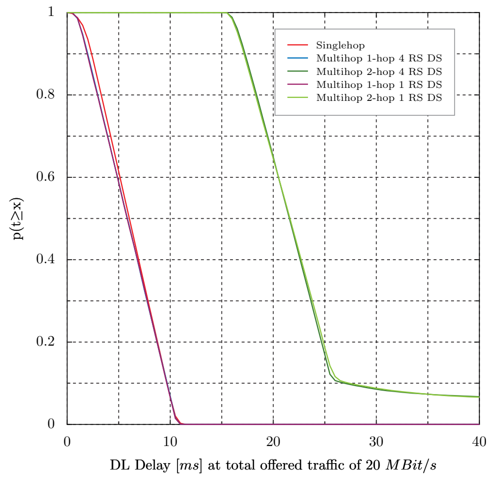


Fig. 8. DL delay of Throughput Scenario

the following frame.

4) The PDU is scheduled for the second hop in the next frame and reaches the SS after about $15ms$.

The minimum delay of the uplink traffic of a remote SS is lower than in downlink. For explanation the journey of a uplink PDU is listed.

1) The traffic generator starts a PDU at the remote SS immediately before the uplink phase of the SS begins. The PDU can be scheduled directly and does not need to stay in a buffer.
2) The relay station receives the PDU maps the Connection Identifier (CID) and re-injects the PDU in the first hop frame.
3) In the next frame the relay station is scheduled for uplink traffic and the PDU is transmitted to the BS after about $6ms$.

The reason for the lower delay for UL traffic is the burst based schedule for uplink traffic. The RS and the SS are not forced to schedule individual PDUs instead the BS reserves a period of time in which any PDU can be sent. DL traffic is scheduled per PDU which limits the scheduler to consider PDUs which are already present at schedule time.

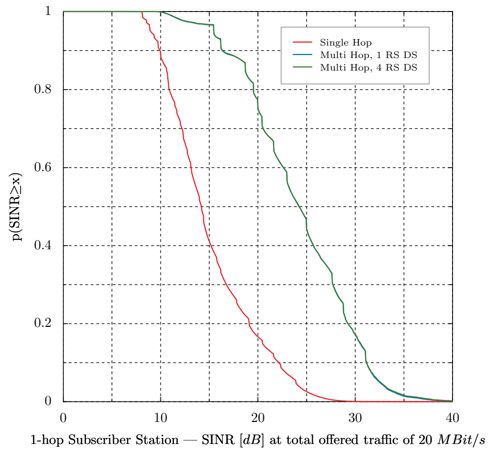


Fig. 9. SINR at 1[st] hop SS

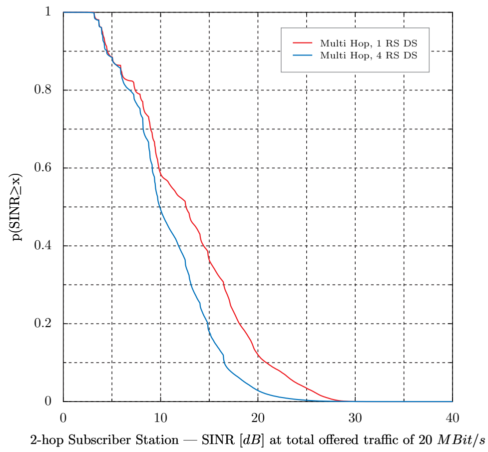


Fig. 10. SINR at 2[nd] hop SS

3) SINR: The SINR of SSs on the first hop differs considerably from the SINR of SSs on the second hop. The overall SINR level is $10dB$ higher for the first hop than for the second hop. The reason for the low SINR for downlink transmissions on the second hop can be found in the spatial reuse that is realized in the scenario. All RSs operate simultaneously and do not avoid the radiation into neighbor subcells. As a result the interference increases at the SSs of the second hop.

It is remarkable that at the first hop the SINR does not decrease below $6.4dB$ which is the minimum value for coding scheme BPSK 1/2. On the second hop several stations do not reach the minimum SINR level and are left out for scheduling. Figure 9 and Figure 10 also show that the SINR level on the second hop falls with the use of more than one data streams.

In the relay enhanced scenario, stations with a higher distance to the BS are served by the RSs. Hence the average SINR for 1-hop SSs increases for almost $10\,dB$.

B. Coverage Scenario

In the *Coverage Scenario* RSs are placed on the border of the cell. Subscriber stations that are located beyond the border

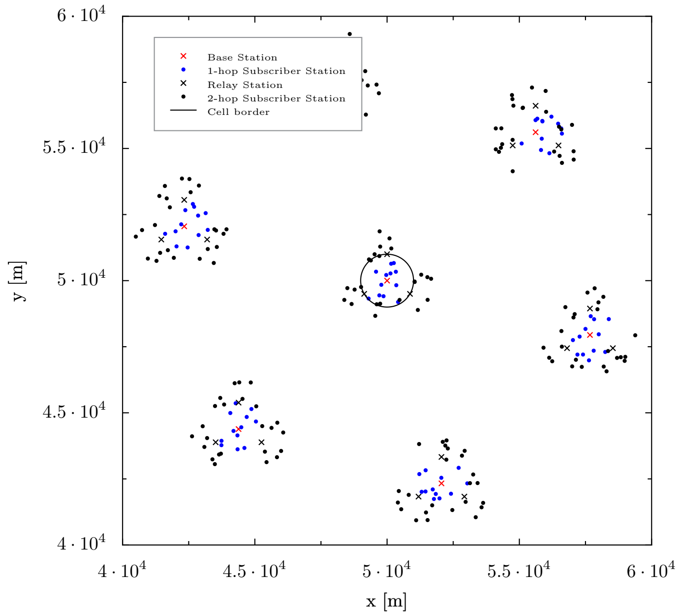


Fig. 11. Position of Stations for Coverage Scenario

of the single hop cell can be served via the RSs. Hence the shape of a cell is extended by the coverage area of the RSs as shown in Figure 2. For the coverage scenario 12 subscriber stations are used on the first hop and eight subscriber stations per relay station on the second hop, see also Figure 11.

For comparison, a single hop reference simulation has been examined that reproduce the same subscriber density as the relay enhanced scenario. Due to the smaller size of the single hop cell the co-channel distance decreases and is chosen with respect to Table I.

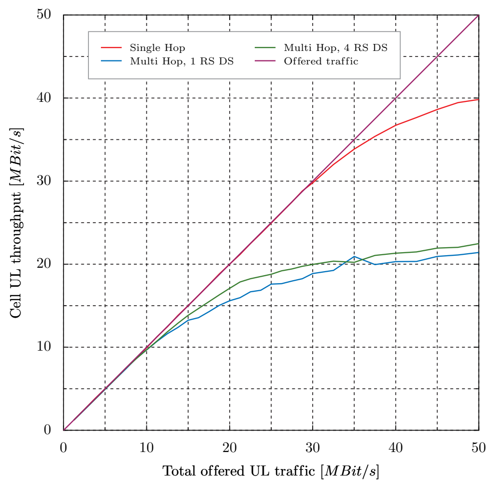


Fig. 12. UL Throughput of Coverage Scenario

1) Throughput: As expected the throughput of the relay enhanced cell decreases in comparison to the single hop reference scenario. Surprisingly the throughput hardly decrease in comparison to the Throughput Scenario. Again several SSs are not served at all. Hence the offered traffic is not carried even at 5 $MBit/s$. Assuming that stations with a low SINR

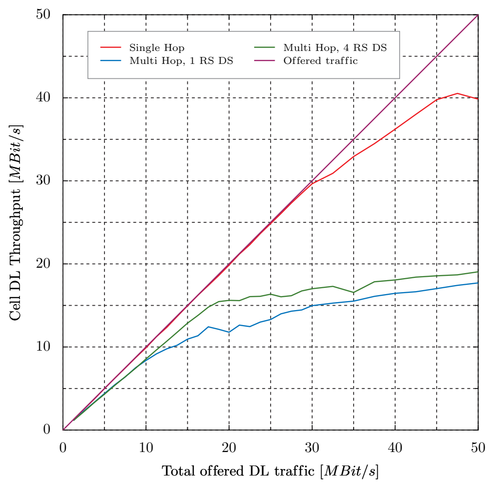


Fig. 13. DL Throughput of Coverage Scenario

can be excluded the cell can carry about 16 $MBit/s$ with four data streams at RSs and 13 $MBit/s$ with one data stream at RSs without getting into overload in downlink. In uplink the cell can carry about 14 $MBit/s$ with four and 13 $MBit/s$ with one data stream at RSs.

The single hop reference scenario can carry significantly more traffic. The cell is getting into overload at about 30 $MBit/s$ downlink traffic and 32 $MBit/s$ uplink traffic.

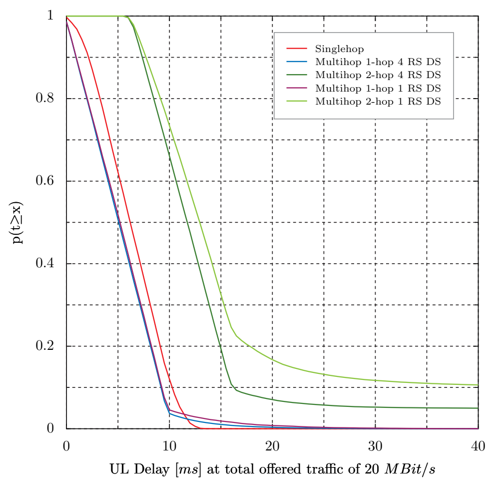


Fig. 14. UL Delay CCDF of Throughput Scenario

2) Delay: Compared to the Throughput Scenario the delay results of the Coverage Scenario do not differ much. Again the minimum DL delay for the 2-hop SSs lies at 15 ms. It is remarkable that in the case of four data stream at RSs the 2-hop DL delay does not stay on a level above 0 like in UL. This means that the cell does not operate in overload for all served SSs. However, some SSs are not served at all and are not considered in this graph.

3) SINR: In the SINR graph of the 1-hop SSs the influence of the decreased reuse distance of co-channel cells is clearly visible. In the single hop simulation the overall SINR level of the 1-hop SSs is about 4 dB lower than in the multi hop

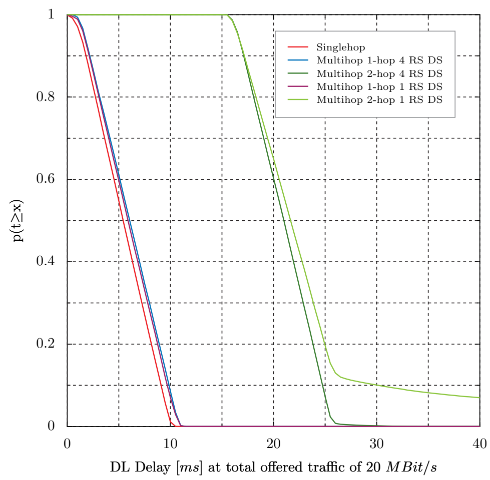


Fig. 15. DL Delay CCDF of Throughput Scenario

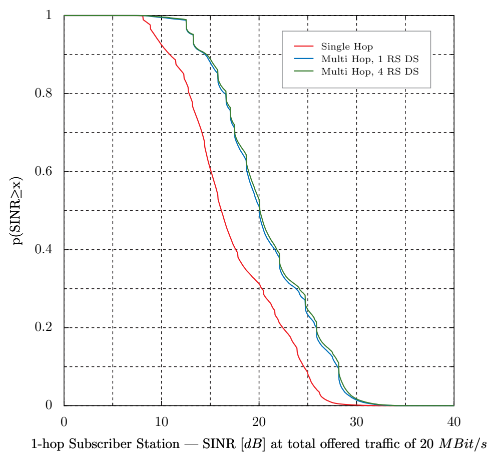


Fig. 16. SINR at 1-hop SS

scenario. In both scenarios 1-hop SS are always served with a sufficient SINR.

The SINR level of 2-hop SSs is worse. Only about 80% of transmitted packets, including MAP PDUs, are transmitted with a sufficient SINR. Again the simultaneous operation of the RSs increases the interference at 2-hop SSs. A satisfactorily operation is hardly possible, even at a low traffic level.

V. Conclusion

The subframe concept has been implemented into the WNS. For this, a framework has been developed that makes a flexible configuration of frame based protocols possible. Two scenarios have been evaluated by means of the implemented simulator. The first scenario tries to increase the BS capacity by placing relays half way between the BS and the cell border. The second scenario extends the BS coverage by placing fixed relays at the cell border.

The results show that intra-cell interference due to spacial reuse of subcells is becoming the limiting factor for throughput performance of the cell. Since the multi-hop subframe is not coordinated between RSs, 2-hop transmissions jam each others subframe phase. This is the reason for the scanty performance

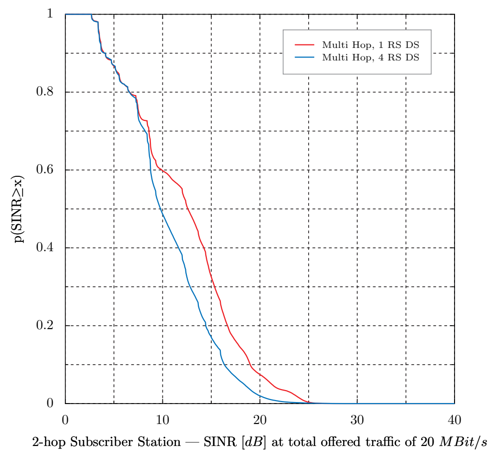


Fig. 17. SINR at 2-hop SS

of 2-hop transmissions in the cellular network. A promising approach to overcome the intra-cell interference is to restrict the RSs transmissions to a Time Division Multiplexing (TDM) operation. In that case, subcells would not disturb each others transmissions with the drawback that subframe allocations would take more time in the MAC frame.

The results also show that coverage extension of a cell with the help of RSs is possible. The covered area of the relay enhanced cell is three times the covered area of a single hop cell.

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