Investigation of Interference Conditions in BFWA System Applying Adaptive TDD

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***Abstract*—**In a BFWA (Broadband Fixed Wireless Access Network) the evolved SINR (Signal to Interference plus Noise Ratio) is relevant influenced by the applied duplex method. The TDD (Time Division Duplex), especially adaptive TDD method has some advantage contrary to FDD (Frequency Division Duplex), for example the spectrum efficiency and flexibility. However these methods are suffering several new interference situations that can't occur in a FDD system. This leads to reduced SINR in the covered area what could cause some connection outages. Therefore, countermeasure techniques against interference are necessary to apply in TDD systems. Synchronization is one way to handling the interference. In this paper the TDD systems – applying different system synchronization degree - will be compared by the evolved SINR at different locations of the BFWA service area and the percentage of the covered area by the system.

***Keywords*—**Adaptive TDD, BFWA networks, duplex methods, intra system interferences.

I. Introduction

The BFWA (Broadband Fixed Wireless Access) networks are the new instruments to provide true broadband services everywhere and every time to everyone applying terrestrial cellular point-to-multipoint networks, wherein both the TSs (Terminal Stations) and the BSs (Base Stations) have fixed locations. These systems have a lot of advantages compared to the wired networks. The fast, cheap and most flexible installation must be mentioned. These systems can be deployed in some areas, where the wired solution would be hard to install or it would cause the demolition of the land [1].

BFWA systems can be applied in several areas. There are applicable for providing high speed Internet, transferring high speed multimedia (video, sound) data. It can be used for feeder network of GSM, UMTS and B3G/4G systems, and it can replace some wired solutions. The BFWA is the part of the heterogenic network vision by the European IST project BROADWAN, which has the goal “Broadband services for everyone” in Europe in the near future [2].

In the PMP (Point-to-Multipoint) networks two duplex techniques are the most prevalent, the FDD and the TDD. TDD systems are known to be more flexible. This method has the major advantage that accommodation to asymmetric traffic demands could be achievable. Changing the length of time slots assigned to downlink and uplink communication the spectral efficiency could be extended than applying TDD (with fixed time slots) or FDD (with fixed bandwidth), when the transfer demands are varying in time. In this case this duplex technique called ATDD (Adaptive Time Division Duplex) can be applied. Until now the major part of the traffic have constituted that broadcasting of TV programs. But now there are trends – downloading and exchanging video, music etc. through the Internet - that requires higher system uplink capacity. Large flexibility will be needed in order to adapt the system's uplink versus downlink capacities to changing user demands. Hence providing high capacity both uplink and downlink to individual users is required in the future. In this situation the spectrum efficiency and flexibility offered by adaptive ATDD is needed [3].

The paper is organized as follows: Section 2 presents the applied duplex methods in the PMP (Point-to-Multipoint) networks. Section 3 describes the interference situations that can occur in a BFWA system and the degrees and those affects on SINR of synchronization. Section 4 represents the assumed simulated network's parameters. Section 5 shows simulation results. Conclusions are given in Section 6.

II. Duplex Methods

In a network that uses FDD technology downlink and uplink uses separate dedicated bands for each communication direction, respectively. If these bands are well separated (by applying sufficient bandpass filters and/or the duplex distance is large enough) the two direction of communication don't disturb each other, or that distortion is negligible. In this case all TSs receive interference just from BSs and similarly just TSs causes interference at the BSs.

In a network applying TDD transmission and reception use the same carrier frequency but in disjoint time slots. It follows from this that this technique is more spectrum-sparing than the FDD. Another advantage of TDD is its flexibility. Moving the time boundary between downlink and uplink (as shown on Fig. 1) results in an asymmetric throughput and an efficient accommodation to the subscribers requirements. When the ratio between the assigned time intervals to downlink and uplink varies in time the TDD is called dynamic or adaptive TDD (ATDD) [3].

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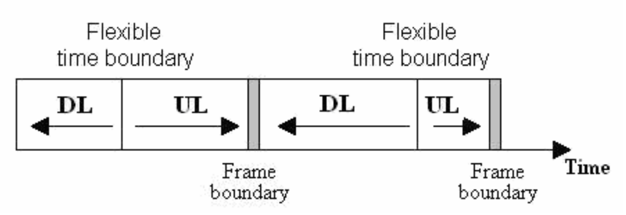

Fig. 1 Varying time boundary in ATDD frames [3]

III. Interference Scenarios

In a PMP communication network all stations (both BSs and TSs) produce and suffer interference. Those stations cause the highest interference which uses the same carrier frequency than the suffering station. As it was mentioned above that in a system applying FDD there are only two kind of interference BS-to-TS (in downlink direction) and TS-to-BS (in uplink direction).

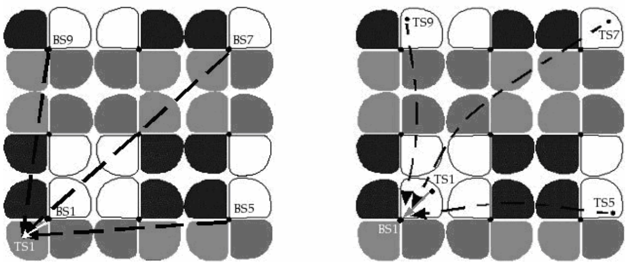

Fig. 2 Dominant interference routes in downlink (left side) and in uplink (right side) cases in a BFWA system applying FDD [4]

Figure 2 depicts the schematic BFWA system. The service area is covered by 9 cells and each cell is divided further to four sectors. The colors of the sectors represent the different carrier frequencies (not well separated consequently signals carried on different frequencies may disturb each other) applied in them, so in a cell FDMA is assumed. On the pictures the most dominant interference routes are signed in both directions. Accordingly the evolving SINR on the service area is lowest at the sector borders and diagonals in downlink case.

Contrarily applying ATDD in a PMP network (both directions uses the same frequency band as in conventional TDD) additional interference sources, what caused by transmitting signals at the same time from different BSs and TSs, would cause the dominant part of the cumulative interference level at the receiver.

The explanation of this phenomenon is depicted on Fig. 3. This figure shows two sectors communication in time, one frame period each. The light grey marks downlink and the white marks uplink communication. In the time interval marked with dark grey color the direction of communication are differing in the sectors. Therefore the BS located in Sector 2 produce interference at BS in Sector 1 because that is already in receiving mode. Meanwhile TS2 in Sector 2 suffers interference from TS1 located in Sector 1.

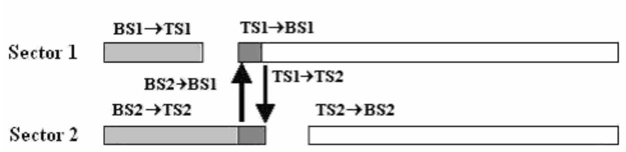

Fig. 3 Additional interference in ATDD [3]

It shows that in an ATDD system additional interference could occur compared to FDD or TDD systems. Four kind of interference are possible in an ATDD system: BS-to-BS, BS-to-TS, TS-to-BS and TS-to-TS. Assuming sharply directed TS antennas with high main lobe gain, the TS-to-TS kind has the least probability because the randomly located terminals have off-chance to be in one another main direction and also have the same carrier frequency. However, when it is the case the caused interference may be significant because of the high gain of the antennas. Similarly, the TS-to-BS interference has likewise low chance compared to TS-to-TS interference and the caused interference is a bit lower serious. BS-to-TS interference always occurs but usually the level is not so notable because of the high distance between the transmitter and the suffering antennas. The highest the interference between to BSs because adjacent sectors – in different cells – usually use the same frequency and the distance between them is not considerable. Furthermore, a low SINR at a BS causes a serious problem, the whole sectors communication could be beyond possible. Consequently the BS-to-BS interference is critical and most significant in the evolving SINR in the ATDD systems. Decreasing this kind of interference is the most important in the time divided duplex networks.

A possible technique for this purpose is the network's synchronization. Time division duplex systems can be classified according to the degree of synchronization. From the less to most flexible network, are: whole network-, cell- and sector synchronization. The latter two are most likely as they permit greater system flexibility. Also there are two levels of synchronization: frame synchronization – when the TDD frames are aligned in time (measured on the BS(s)), but the length of downlink and uplink intervals within the frames can be different in each sector – and signal direction synchronization – when also downlink and uplink intervals are synchronized [3].

Different system synchronization degrees of synchronization are depicted on Fig. 4. The little rectangles symbolizes the frame timing in a sector, the grey-white ratio illustrates the downlink-uplink interval lengths. The columns rows of the table represents the different synchronization cases giving the time positions of the frames (frame boundary) and the downlink-uplink time interval (time boundary in a frame) of four neighbor sectors of two cells of a schematic BFWA network.

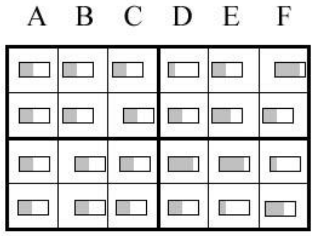

Fig. 4 Different system synchronization degrees with decreasing synchronization level from A to F

Column 'A' represents the synchronization case when both frame and time boundaries are aligned in time in each sector of the whole network. In the case represented by column 'B' the frame and time boundaries are still aligned in time in the sectors belonging to the same cell. Although, these boundaries in sectors belonging to different cells, they can be totally dissimilar. In case 'C' only the time boundaries are aligned in each sector in contrast with the frame boundaries, that are not aligned in time not even in those sectors which belong to the same cell. In synchronization cases 'D', 'E', and 'F' the uplink-downlink time ratio could be dissimilar in each sector. The frame boundaries are aligned in time in the sectors of the whole network (case 'D') or in cells only (case 'E'). Case 'F' equals to asynchrony.

In the case of TDD systems the evolving SINR is highly influenced by the applied synchronization by the network. Synchronizing the whole network (case A) and the signal direction (uplink/downlink) no additional interference situations – when compared to FDD systems – would appear. But the flexibility and hence most of the potential capacity gain achievable by dynamic and/or asymmetric traffic conditions would then be lost. Conversely, no synchronization at all (case F) would result in interference between BSs, between sectors of each BS, potentially at all the time. Trade-offs will be needed between system flexibility and risk of interference. In the following sessions case comparison study will be carried out to be able to find the trade-off between the level of synchronization and caused interferences influencing the system spectral efficiency and system complexity and/or flexibility.

IV. System Assumptions

In order to compare systems using different synchronization, computer simulations were accomplished in the 38 GHz frequency band. The simulated BFWA network model is depicted on Fig. 5. The investigated system contains 9 BSs in a regular 3 x 3 BS configuration with four 90° sectors per cell operating at different carrier frequencies (i.e. applying FDMA in a cell), respectively. The BFWA cell has a size of 6 x 6 kms, therefore a sector has a size of 3 x 3 kms realizing an 18 x 18 kms BFWA coverage area model in calculations. Accordingly to the 4 sectors, 4 different frequencies were applied. The different frequencies are signed on Fig. 4 by different colors. In each sector TDMA method and LOS condition (because the high carrier frequency) were assumed. All the channels use the same polarization. A constant thermal noise power was considered at each transceiver. The TS antennas are sharply directed towards the nearest base, placed 60 meters height and the BS sector antennas have 90° main lobe installed at similar height.

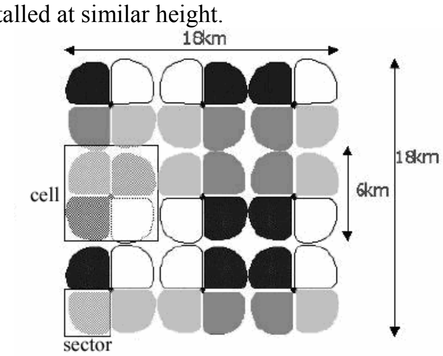

Fig. 5 Cell and sector layout [4]

Furthermore, TSs are power controlled in order to the received signal power at BS be the same from each TS in the sector, independently from their location.

Before starting the simulation terminal station locations were randomly determined placing a randomly varying number of TS from 5 up to 10 in each sector. By investigating the systems applying different synchronization degree this TS position remain the same to achieve comparable results. Three frame time length was simulated for each synchronization cases from A to F.

In the sectors that operate in downlink communication mode the SINR is measured at the TS. The desired signal (carrier) is sent by the closest (own) BS. Interfering signals come from all the other antennas which are in transmitter mode at the observed moment, dominating those which have the same carrier frequency as the desired signal. In the sectors operating in uplink direction at the given time slot, the SINR measured at the BSs. The desired signal received from the currently active TS located in the sector, all the other operating transmitters in the system cause interferences.

V. Simulation Results

To compare different synchronization cases SINR maps and covered area given in percent of the BFWA system service area were introduced. The SINR maps show the evolved SINR values in the investigated BFWA network. In each map SINR values (in dB) are given in color scale. These maps give the values of interference conditions at different snapshots, so they are valid only in those moments. On the map in a downlink sector, the color of a point shows the SINR value evolved at the terminal station installed at that location. In the uplink sectors, the color of a point shows the SINR value evolved at the base station, which belongs to the terminal stations located there. In uplink case all the points in a sector has the same SINR value, because the desired signal level values are constant through the usage of the transmitting power calibration at the TS, and the interferer signals are the same in average at the receiver.

In synchronization case ‘A’ the direction of communication is the same in all sectors of the whole network at every time. Therefore the evolving SINR is exactly the same as in a system applying FDD for both up and downlink, respectively. Fig. 6 shows the evolved SNIR using this kind of synchronization. The map on the left side (downlink in each sector) can be confronted with the system layout shown on Fig. 5. The light areas with high SINR are near to BSs, the critical territories are the sector borders and corners of the covered area. It must be mentioned that these conditions are static in time. Please observe that on the map on the right side (sectors in uplink mode) the SINR values are constant inside each sector due to TS transmit power calibration to achieve the same received power at the BS. Henceforth the sectors with uplink mode can be easily recognizable by the same color of this territory.

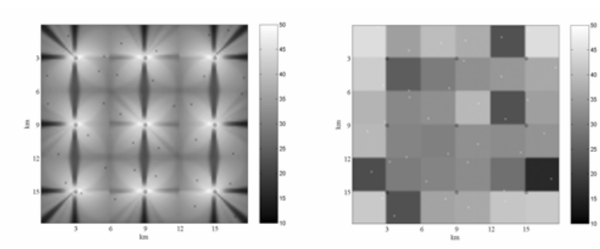

Fig. 6 The evolved SINR maps at two moments in case ‘A’

To compare the efficiency of the different synchronization cases numerically the percentage ratio of the covered area of the BFWA system was also considered for each case, respectively. Different modulation methods have been also considered by coverage calculation applying 4, 16 and 64 QAM, respectively. It was examined that how much percentage of the service area reaches the minimal SINR level in order to have 10^{-6} SER (Symbol Error Ratio) applying the assumed modulations [5].

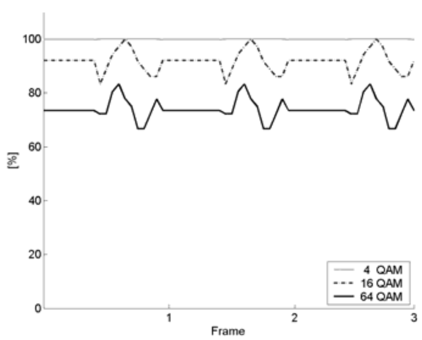

Fig. 7 Percentage of the covered area by different modulation in a three frame length time interval in case ‘A’

Fig. 7 depicts the changing percentage of the covered area by different modulation in a three frame length time interval in case ‘A’. Half frame interval was assumed both to uplink and downlink communication, and all the frames begin with downlink. The evolving SINR snapshots applying case ‘D’ in the BFWA network is shown on Fig. 8 and the time dependent percentage of the covered area on Fig. 9.

In this case the interference conditions changes continuously; not even the downlink SINR is static. At a moment early in a frame as it can be seen on the map ‘a’ most of the sectors are in downlink mode, the few uplink sectors have low SINR due to BS-to-BS interferences. The map ’d’ represents the evolved interference conditions at a moment near to the end of a frame, so most of TSs transmit only in a few sector transmit the BSs. On the other two maps (‘b’ and ‘c’) interference conditions at moments in the middle of the frame are illustrated. In this cases the area with low SINR are escalated.

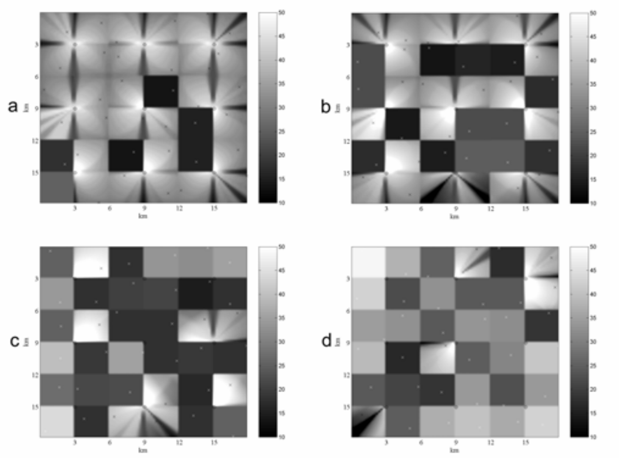

Fig. 8 The evolved SINR maps at four moment in case ‘D’

In some of the downlink directed sectors the SINR is significantly reduced in a part of the sector due to a TS-to-TS high level interference.

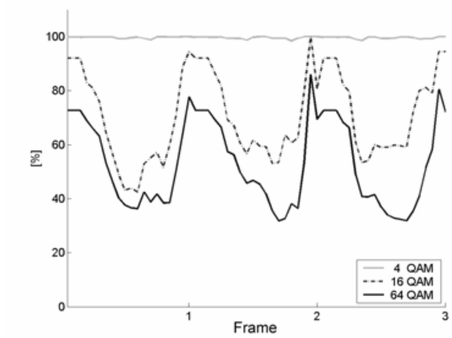

Fig. 9 Percentage of the covered area by different modulation in a three frame length time interval in case ‘D’

On Fig. 9 the curves still have periodic characteristic as an effect of frame synchronization, but in the middle of the frames the percentages dramatically decreases due to the adjacent sectors with opposite communication directions, so the BS-to-BS interferences. It must be mentioned that the major part of the whole service area (>98%) can be provided with 4 QAM modulation in both network synchronized case.

Cell synchronization gives more flexibility (and enable less signaling) to the network. The evolved SINR at four snapshots are depicted on Fig. 10 in the synchronization case 'B'.

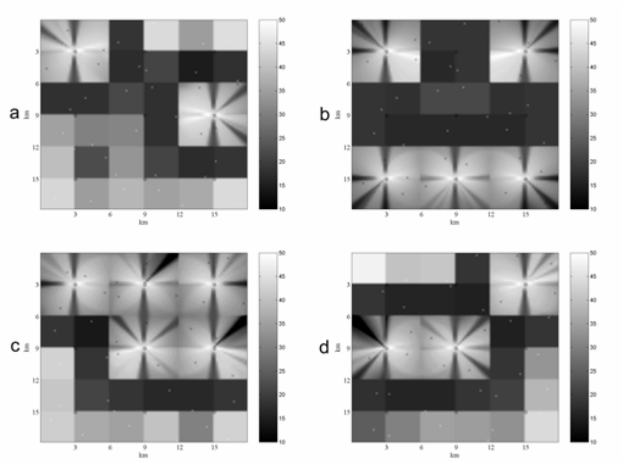

Fig. 10 The evolved SINR maps at four moment in case 'B'

In this case there are always adjacent sectors (belonging to different cells) which have the same frequency therefore the BS-to-BS interference always occur. In some situations much of the service area could be suffering from this interference as it can be seen on the map 'b'. Moreover in the downlink sectors the users located in the sector diagonals receive more interference.

Fig. 11 depicts the changing percentage of the covered area by different modulation in a three frame length time interval in case 'B'. Please observe that with 4 QAM modulation the major part of the territory is still coverable but with the other modulations even less percent of the area could be covered. The 16 and 64 QAM curves are similar in the whole interval with high dispersal.

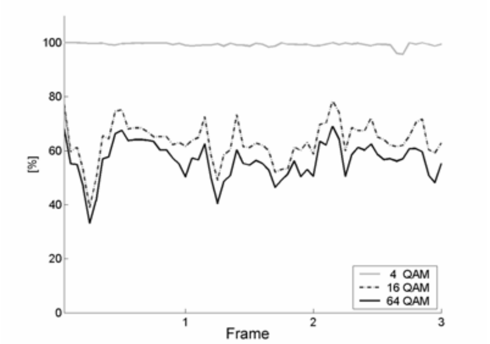

Fig. 11 Percentage of the covered area by different modulation in a three frame length time interval in case 'B'

In case 'E' the evolved SINR at different moments are shown on Fig. 11. In this case the TS-to-TS interference is more often, it could cause that even communications outage with 4 QAM modulation.

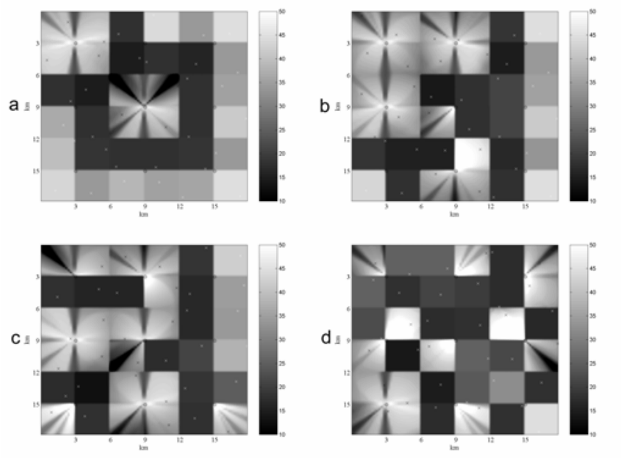

Fig. 12 The evolved SINR maps at four moment in case 'E'

Fig. 12 depicts the changing percentage of the covered area by different modulation in a three frame length time interval in case 'E'. Please observe that with 4 stage QAM modulation the major part of the service area is still coverable but in some moments this percent is decreases due to high level TS-to-TS interferences. The coverable area with the other modulations decreased further.

Applying no synchronization guarantees the most flexible network what an ATDD can reach. Nevertheless the problem of interference is the least handleable. Fig. 13 depicts the evolving SINR in the BFWA network applying synchronization case 'F'.

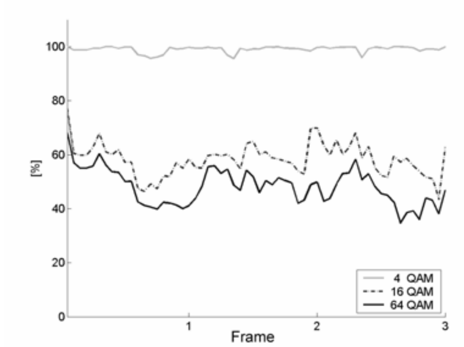

Fig. 13 Percentage of the covered area by different modulation in a three frame length time interval in case 'E'

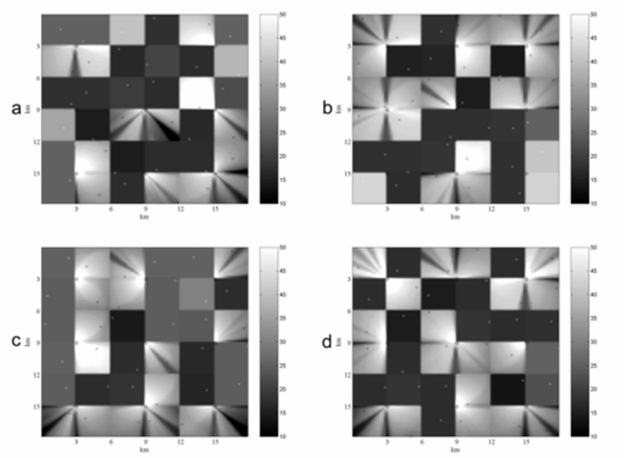

Fig. 14 The evolved SINR maps at four moment in case 'F'

Observing the four maps it can be seen that in this case in half of the sectors the direction of the communication is downlink and uplink at all time. Therefore there are always BS-to-BS and TS-to-TS interferences. Consequently, the coverable area with the higher order modulations have been more reduced than in the other synchronization cases as it is shown on Fig 15. Assuming 64 QAM in average less than the half of the service area can be provided. Even so please observe that the major part of the area is still coverable with 4 QAM in the case of asynchrony ('F').

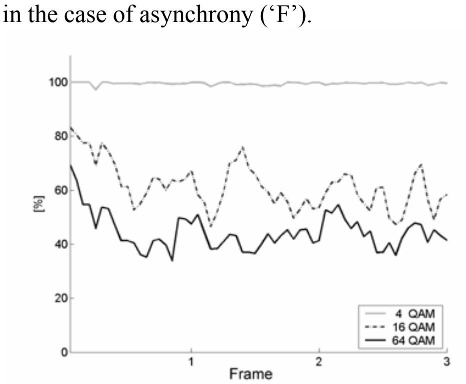

Fig. 15 Percentage of the covered area by different modulation in a three frame length time interval in case 'F'

TABLE I
SUMMARY: AVERAGES OF PERCENTAGE RATIOS OF COVERED AREAS IN DIFFERENT ANALYZED SYSTEMS

		$SER=10^{-3}$	$SER=10^{-6}$
Case 'A'	4 QAM	100	99,8
	16 QAM	95,4	91,2
	64 QAM	78,3	73,5
Case 'D'	4 QAM	99,8	99,6
	16 QAM	76,9	71,1
	64 QAM	60,6	53,2
Case 'B'	4 QAM	99,6	99,3
	16 QAM	69,8	68,6
	64 QAM	60,9	56,3
	4 QAM	99,6	99,1
Case 'E'	4 QAM	99,6	99,1
	16 QAM	64,9	58,3
	64 QAM	51,4	48,1
Case 'F'	4 QAM	99,7	99,5
	16 QAM	67,9	61,4
	64 QAM	48,1	44,5

The average values of covered areas of various systems are displayed in Table I. It is clear that the most favorable case, considering SINR, when the whole network is signal direction synchronized (case 'A'). However, dynamics in traffic on both of up and downlink could not be served efficiently. The coverable area is almost the same applying frame synchronization in the whole network or signal direction is synchronized by each cell. In a system without synchronization scant percent of the service area could be provided with higher order modulation.

VI. CONCLUSION AND FUTURE WORK

This paper's goal was to compare the various synchronization techniques considering the evolving SINR and the covered area of BFWA network using adaptive TDD method. Constant system QoS (10^{-6} SER) was a requirement by analyzing the system performance of different degree of synchronization and applying different order QAM. It is demonstrated that in adaptive TDD systems the surplus interferences reduces the SINR on the covered area remarkably. A method to mitigate these additional interferences is synchronization but using this technique the advantage of adaptive TDD – the high flexibility – will be lost. However, the changing traffic demands on both of up and downlink could not be achieved with high efficiency. Compromise is needed between flexibility and the system's capacity.

As future work efficient interference mitigation techniques will be researched for example diversity techniques or power control.

The model used by the simulation also could be improved. The applied model was defined on totally flat terrain, so digital terrain maps should be considered.

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