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Re:	Proposed new concepts
Abstract	In this document, the benefits of the introduction of switched-beam antennas in broadband wireless access networks, namely system capacity improvement, are presented. This is achieved due to interference reduction (spatial filtering) and coverage area management strategies (directivity increase, sector reshaping). However, the introduction of switched-beam antennas in the system scenario is not straightforward. We propose an adaptation of the system protocols based on typical frame structures that will allow the introduction of switched-beam antennas with minor protocol overhead.
Purpose	Contribution to the proposed new concepts in session #26
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Switched beam antennas in millimetre-wave band broadband wireless access networks

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1. INTRODUCTION

Recently, the use of smart antennas at the Base Station (BS) in broadband wireless access (BWA) networks has been proposed. The introduction of such technology enhances system: improved CNR due to higher antenna gain, reduction of delay spread and multi-path fading, reduction of the C/I level due to spatial filtering, spectrum efficiency and capacity enhancement, outage probability reduction and BER improvement, etc [1-3]. Several kinds of smart antennas have been considered: switched lobe antennas, switched beam antennas, adaptive arrays or space-time coding [4]. However, in LMDS/MVDS systems operating at millimeter-wave frequencies, the use of adaptive arrays or space-time coding is not possible at the moment due to stringent processing speed and I/O speed requirements, which can not be satisfied by currently available digital signal processors [5]. In BWA scenarios, such as considered in standard systems [6, 7], switched-beam antennas (SBA) seem to be the most feasible option to introduce smart antenna features, due to their relatively low complexity and high advantages [5]. In this document, the introduction of a SBA in the BS is proposed.

1.1. Switched-beam antenna operation

As depicted schematically in figure 1, this antenna has a directive radiation pattern capable of being scanned to a set (typically a power of 2) of angular directions or beam positions, so that the whole sector is divided in several micro-sectors. Each micro-sector has a pre-defined beam pattern with maximum gain placed in the center of the beam. This beam-switching approach matches perfectly with a time-based system (TDM/TDMA), as the BS antenna is illuminating only in the desired direction in the assigned access instant.

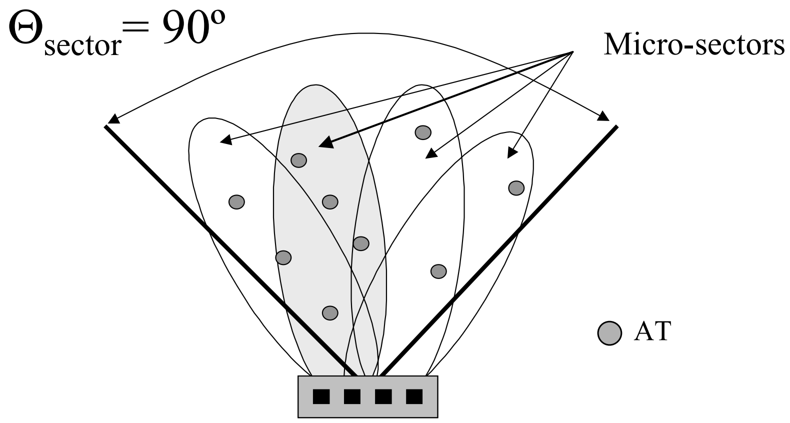

FIGURE 1. Beam-switched antenna scenario

Therefore, the BS cover the service region using a narrow beam synchronized to the sequences of the time assignment. The antenna scanning time, which turns up to be critical for this operation mode can be reduced even to the range of nanoseconds [8]. In section 2 of this document, it is showed how the use of SBA improves significantly the C/I level at the BS, which lead also to improved capacity.

1.2. MAC protocol adaptation

However, the use of SBA has some implementation issues that should be taken into account, for instance the distribution of broadcast information to all users within the sector covered by any BS. Due to the switched-beam approach, the broadcast information is not transmitted simultaneously to all the subscriber station (SS) within the sector. In addition, the SS should be capable of accessing "simultaneously" during some periods within the uplink frame, in a contention or polling mode. This is clearly unfeasible with a SBA, and therefore such protocols must be adapted for the proposed scenario. This adaptation is usually implemented adding more protocol overhead (i. e. transmitting the broadcast messages in all the possible beam directions) [5]. In section 3 of this document, the adaptation of the MAC protocols to the SBA scenario is evaluated.

2. CAPACITY IMPROVEMENT: INTERFERENCE REDUCTION

One of the most remarkable benefits of SBA is the capacity improvement due spatial filtering. This property of the SBA scenario leads to an increase of the gain link and at the same time a reduction of the system co-channel interference. This way, a higher number of SS would be able to employ higher order modulation formats, increasing the spectrum efficiency and consequently the overall network capacity.

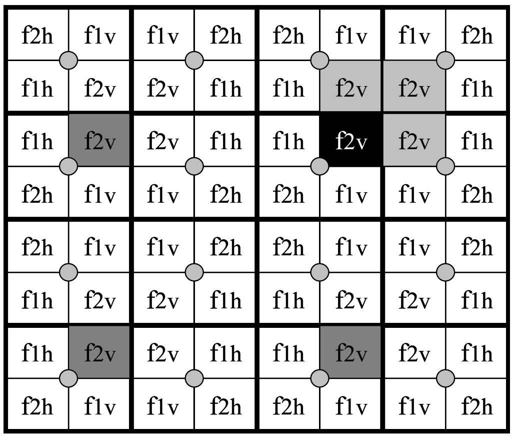

FIGURE 2. Considered reuse pattern: two frequencies and two polarisations. The grey coloured act as co-channel interference sources. The dark grey sectors are the dominant co-channel interferers.

In the proposed frequency reuse patterns, several sectors acts as co-channel interference sources. For instance, as may be seen in figure 2, in the downlink direction the SS antenna receives incoming signals from three different sectors and what is most important, during all the frame duration. The introduction of a SBA scenario would lead to a reduction of the situations in which the SS receives interferences from these three sources, as the pointing direction of the SBA at each BS depends on the traffic pattern of each sector which may be supposed to be incorrelated. Typically, the SS would collect interferences from one or none of these sources during the main portion of the frame, leading to a reduction of the mean C/I level. A similar situation occurs in the uplink direction. The narrower beam of the SBA receives less interference power from the SS transmitting at the same frequency at different sectors. It should be remarked that this interference reduction is obtained and simultaneously the gain link is increased.

Figure 3 shows the outage probability as a function of the required C/I level and for different values of the antenna beamwidth (considering a sectorial 90-degrees or a 4-, 8- or 16-beam positions SBA). The considered cellular reuse pattern uses 2.5-km cells with four 90-degrees sectors employing two frequencies and two polarizations [5, 6], in which three co-channel interference sources are located at 10, 10 and 14.14 km from the BS as shown in figure 2. Downlink system performance has been studied and simulated assuming free-space propagation in the desired signal path, three path-loss exponent ($1/r^3$), shadowing with a standard deviation of 8 dB in the interfering signals paths and a 3-degrees SS antenna beamwidth [9]. As expected, the outage probability increases as the required C/I level increases. However, when a SBA antenna is employed, the obtained outage probability is reduced for the same C/I level. This effect is more noticeable when a SBA with more beam positions, i. e. with narrower beam, is employed. For instance, for a C/I requirement of 20 dB, the outage probability may be reduced to less than a tenth of its value when a 90º sectorial antenna is employed.

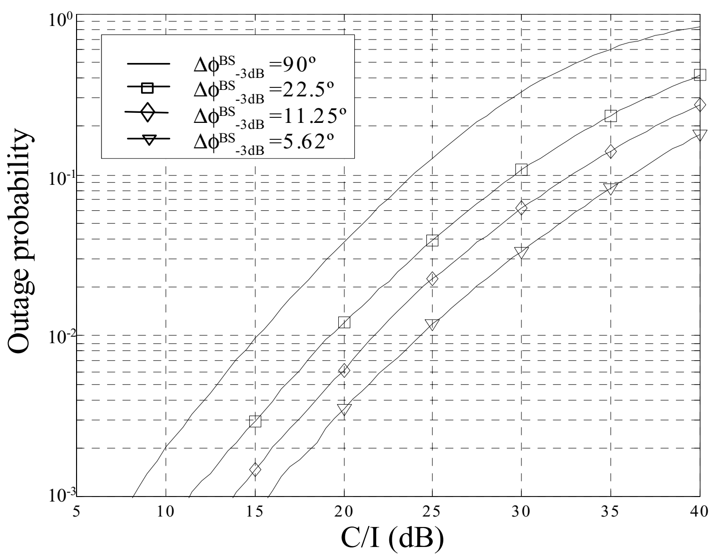

FIGURE 3. Performance improvement using SBA: outage probability as a function of the required C/I level for a 90-degrees sectorial antenna and a 4-, 8- and 16-beam positions SBA.

As a direct consequence of the interference reduction, the SSs may use a higher order modulation format, which would result in an overall capacity enhancement. Figure 4 depicts the radius of the coverage area in which the C/I level required to obtain a 1% outage probability is ensured. As may be seen, the use of a SBA antenna increases the range in which a certain C/I level is ensured, and this would allow more SS operating with higher modulation formats. For instance, the coverage area radius for a 10^{-11} BER employing 16-QAM modulation (required C/I level is 21 dB) is increased from 1200 to 2600 m when the 8-beams SBA is used instead of the 90-degrees traditional antenna. Again, this effect is more evident when a SBA with more beam positions is employed.

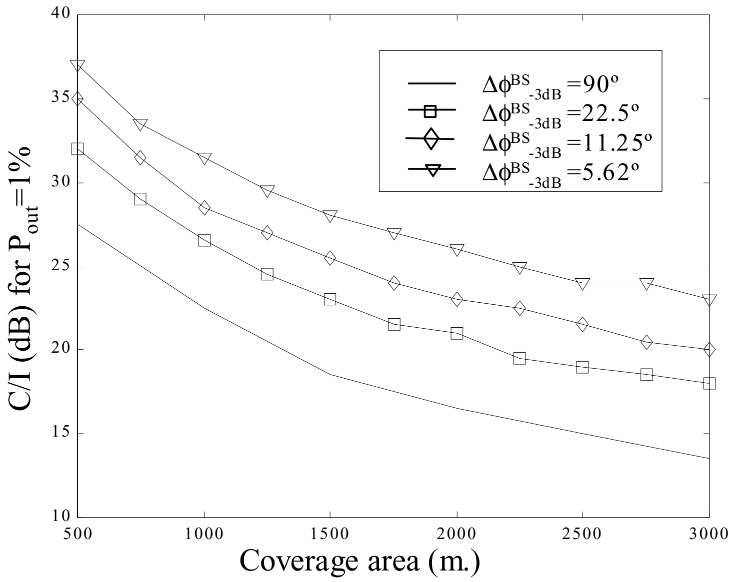

FIGURE 4. Overall capacity increase: coverage area in which a 1 % outage probability is ensured.

3. PROTOCOL ADAPTATION

As a drawback of the SBA scenario, the broadcast of information or the provision of contention access is clearly infeasible. The introduction of SBA in BWA networks requires the adaptation of the system protocols, which is typically implemented adding some control overhead [5]. In this section the viability of the protocol adaptation is studied by means of simulations for the broadcast of protocol control information case. The proposed solution is based on the replication of the control information with an specific overhead minimisation.

3.1. Frame structure

Both BS and SS transmit fixed length frames of 1 ms. FDD and TDD duplexing are supported, however TDD is preferred due to a more efficient bandwidth management. The downlink sub-frame consists in control and data transmission sub-periods and starts with a preamble for system synchronisation. The control information operates in a broadcast mode and allocates the available bandwidth in the frame employing maps. The uplink consists of signalling and SS transmission sub-periods, both defined in the previous control information. The signalling is typically used for unsolicited SS transmissions (i.e. registration, traffic bandwidth demand after long inactivity periods, etc) and operates in contention or polling modes.

The protocol control information mainly consists of maps that indicate transmission events (i.e. starting instant and allocated bandwidth) within a frame. The Downlink Map (DL_MAP) message defines the access to the downlink information. DL_MAP messages includes frame number, BS identifier, and for each physical transmission mode indicated by the Downlink Interval Usage Code (DIUC) and the allocated starting symbol. The Uplink Map (UL_MAP) message allocates the instants for the different access to the upstream channel (contention, polling, granted access, etc.). In this case, the UL_MAP contains the starting symbol, the SS identifier and the Uplink Interval Usage Code (UIUC). Both DIUC and UIUC describe the physical transmission mode in terms of modulation, channel and code coding, purpose, etc. The considered DL_MAP and UL_MAP messages are represented in figure 5.

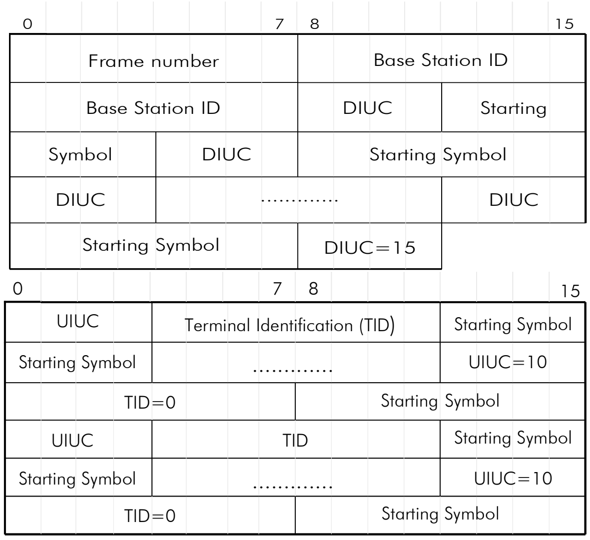

FIGURE 5. Map format for DL-MAP (up) and UL-MAP (down) considered in the simulations.

3.2. Slot-based beam-switching approach

As stayed before, the control information, DL_MAP and UL_MAP, must be broadcasted to each SS registered in the BS coverage area. As no 90-degrees antenna is present, this information must be replicated by all the SBA beam positions that cover the sector. As a consequence of this replication of the control information, a degradation of the system throughput due to the increased protocol overhead is expected. Data information is treated in a slot-by-slot basis. In this approach, each information slot is transmitted through the beam that covers the BS that the information is addressed to. Therefore each slot is transmitted using a different beam depending on the SS location.

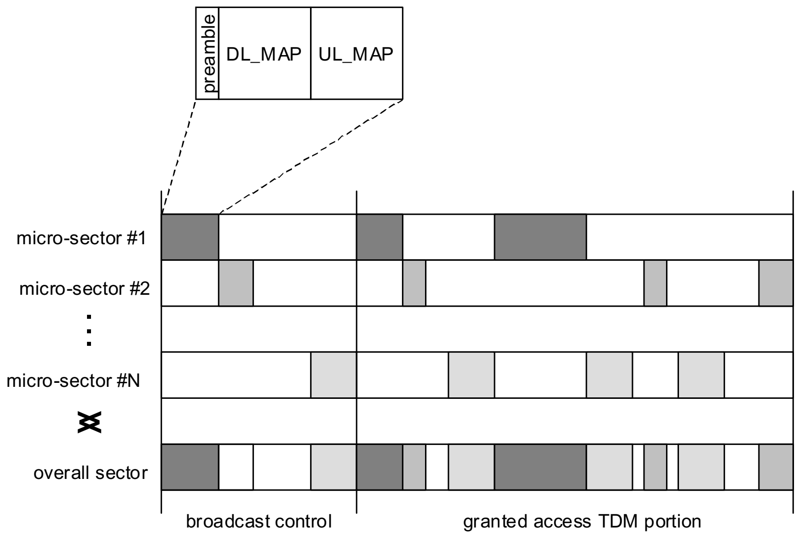

FIGURE 6. Slot-based beam-switching approach in the TDD downlink subframe structure.

The minimisation of the control information overhead consists of the minimisation of the total DL_MAP size and minimisation of the total UL_MAP size. In the downlink direction the map size is reduced mapping in the DL_MAP dedicated to a given beam position only the data sections addressed to SS located in that beam position. This way, the whole control information required to manage the sector is not mapped and transmitted in every beam position and only the relevant information for each beam position is introduced in each DL_MAP. SSs can accurately obtain the allocated downlink interval as the starting symbol information is referred relatively to the beginning of the frame dedicated to each beam position. In a similar way, UL_MAP minimization consists on mapping in the map dedicated to each beam position only the uplink data information concerning to the SS located in the beam coverage area.

Figure 7 shows the total map size when a 4-, 8- and 16-beam positions SBA is employed, using the proposed minimization strategy. The map size is evaluated using typical coding procedures [1,2]: 30 bytes code-words with RS(46,30,t=8) and inner convolutional code of rate ½, QPSK modulation and a minimum map size of 2 code-words. As it may be seen, when the minimization strategy is employed, the total map size converges to the traditional scenario in high load traffic situations (high number of active SS). It may also be observed that in low load traffic situations the total map size has a minimum due to the minimum two code-words size imposed. However, the problem of the system overhead has been overcome in the situation in which it may become critical.

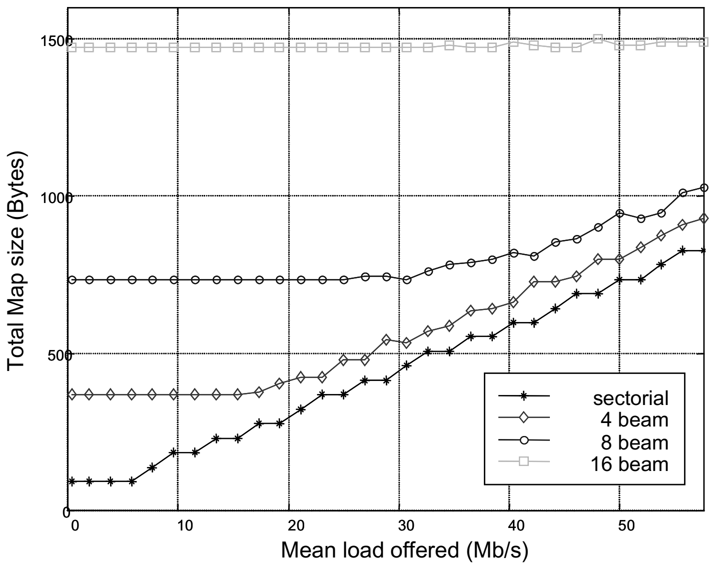

FIGURE 7. Simulation results of the minimization strategy: total map size for a 4-, 8- and 16-beam positions SBA

3. CONCLUSION

The introduction of switched beam antenna scenarios in fixed broadband wireless access has been proposed. Switched beam antenna features lead to an enhancement of the overall system capacity by reducing the co-channel interference. The protocol overhead due to the use of SBA can be efficiently minimized by setting up a proper control information minimization strategy.

Acknowledgement
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