Reflections on Smart Antennas for MAC Protocols in Multihop Ad Hoc Networks

Hend Koubaa
LORIA INRIA - Campus Scientifique - BP 239
54506 Vandœuvre-Les-Nancy Cedex France

ABSTRACT

Smart and directional antennas can be used to improve the throughput performance of wireless communications in ad hoc networks. This improvement consists basically of minimizing collision and increasing simultaneous communications. Directional antennas reduce potential collision zone since data packets are directionally transmitted. Smart antennas are more intelligent than directional antennas since they can dynamically point pattern nulls in the direction of interfering stations. In this paper, we consider the link capacity achieved by a set of portable stations sharing the same medium and equipped with smart antennas. We present an overview of related work based on directional and smart antenna use to improve signal reception. We introduce and discuss the problem concerned with smart antenna use for transmission based on CSMA MAC protocols. This problem consists principally of beam selection and handoff. A CSMA MAC protocol within a station equipped with a smart antenna, has to interact with the physical layer to manage beam use. Our discussion, taking into account hidden node and exposed node problems, is motivated by underlying overhead, symmetry assumption and beacon use.

1 INTRODUCTION

An ad hoc network is a multi hop wireless network in which mobile hosts communicate over a shared channel. It is characterized by the absence of a wired backbone that manages the interconnection between its mobile nodes. The role of the medium access control protocol (MAC) in ad hoc networks is to decide who has channel access on a shared medium. We call a MAC protocol in ad hoc networks, a contention based MAC protocol. The known contention based MAC protocols are Pure ALOHA, Slotted ALOHA and Carrier Sense Multiple Access (CSMA). The CSMA protocol is the most performant. In CSMA, each node tests the channel before using it. In case of collision, back-off techniques are used to check again the channel as in the standard IEEE 802.11.

With pure CSMA, an ad hoc network is still a victim of the known hidden node problem (see figure 1 (a)). The solution adopted to this problem is to introduce a handshaking protocol to inform all the receiver's neighbours that the channel is occupied: the transmitter has to send a Request to Send (RTS) message to the receiver and the receiver has to reply with a Clear to Send (CTS) message. Even though, this solution raises the exposed node problem (see figure 1 (b)). Many protocols in the literature propose MAC solutions based on the handshaking protocol: Sender Initiated Channel Reservation Protocols [1, 2, 3, 4] in which the transmitter initiates communications and Receiver Initiated Channel Reservation Protocols [5, 6] in which the receiver informs the transmitter that it is ready to receive. Other protocols [7, 8] add the use of busy tones to minimize collisions. These works are based on omnidirectional antenna use. Recently, directional and smart antennas have also been considered. We present in the next paragraph the directional and smart antennas.

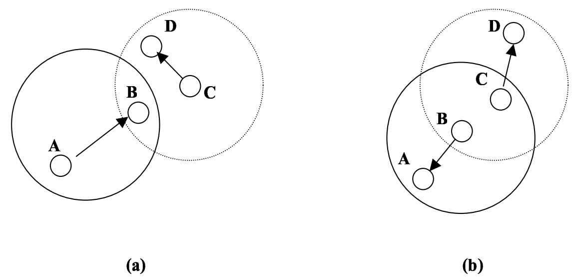

Figure 1: Examples of Hidden (a) and Exposed (b) Node problems. The circles indicate the radio transmission ranges

An omnidirectional antenna is an antenna that radiates and receives equally well in all directions. It has the disadvantage that desired users are reached with only a small percentage of the overall energy sent out into the environment. Its omnidirectional broadcast impacts spectral efficiency and limits frequency reuse. For this reason, directional antennas are designed to have fixed transmission and reception directions. Even though, directional antennas do not overcome the most important disadvantage of an omnidirectional antenna which is interference. The next step towards performant antennas was thus smart antennas. A smart antenna is composed of an array of antennas that can be arranged in linear, circular or planar configurations. Most often, smart antennas are installed at the base station, although they may also be used in mobile phones or laptop computers [9]. Their purpose is to augment the signal quality through more focused transmission of radio signals and to enhance capacity through increased frequency reuse. Their smartness resides in a combination of their Digital Signal Processing (DSP) with the antenna array. Principally, this combination is based on diversity techniques that get benefit from multipath signals.

There are basically two types of smart antennas: switched-beam or fixed beam antennas and adaptive array antennas. A switched-beam antenna generates a multiplicity of juxtaposed beams whose output may be switched to a receiver or a bank of receivers. The role of the DSP in switched-beam antennas is limited to signal strength detection, a fixed beam choosing and switching from one beam to another as the mobile moves. It is to note that beams in this kind of antennas are predetermined and fixed. In an adaptive array antenna which is more advanced than a switched beam antenna, the beam structure adapts to Radio Frequency (RF) signal environment and directs beams to bona fide signals, depressing the antenna pattern in the direction of the interferers [10]. In adaptive array antennas, an algorithm is needed to control the output, i.e. to maximize the desired signal power (e.g.: Applebaum Algorithm and Widrow Algorithm [10]). The difference between both kinds of smart antennas can be resumed as follows: fixed beam antennas focus their smartness in the strongest strength signal beam detection and adaptive array antennas benefit from all the received information within all antenna elements to optimize the signal output through a weight vector adjusting. It is to mention that switched beam antennas outperform directional antennas.

In the present paper, we are interested in smart antennas that are a kind of directional antennas able to transmit/receive in different angles. These can be both kinds of smart antennas since we are based on the capability of communication sectorization.

It is to note that in literature [10, 11, 12], most of smart antennas are exploited to optimize signal reception. It is true that their smartness or their DSP is designed to optimize the quality of reception. Although, we can benefit from this DSP to optimize the transmission. This can be ensured with fixed beam antennas since the task is reduced to fix a beam among several fixed beams. With adaptive array antennas, the task is more complicated since an infinity of beams can be used. Even though, we can at least obtain the same possibilities offered by switched beam antennas.

In this paper we use angle, sector or beam interchangeably to describe a focused beam of smart antennas.

The remainder of the paper is organized as follows: section 2 reviews related work. In section 3 we analyse the problem discussed in this paper. The section 4 and 5 present our solutions for a CSMA protocol based on smart antennas. Finally, conclusion and perspectives are presented in section 6.

2 Related work

Recently, the use of directional and smart antennas has been considered in multihop MAC protocols. This use aims bandwidth improving in wireless networks.

The use of smart antennas is principally based on their smartness and capability of collision minimization: packets can be received correctly in the presence of interfering packets. In the paper [13], the authors have proved that using adaptive array antennas can make the performance of a single hop slotted ALOHA packet radio networks to improve. In [14], the same authors propose an optimization of [13] by the use of a Multiple-Beam Adaptive Array (MBAA) that can successfully receive two or more overlapping packets at the same time. The MBAA is a system where the signals from a set of array elements are combined with more than one set of weights to form several simultaneous receiving patterns [14].

Other works have focused their effort on the optimization of a CSMA protocol by use of directional antennas [15, 16, 17]. These works tend to make possible efficient using of the shared medium. This means principally increasing the number of simultaneous communications in a shared medium by resolving the exposed node problem. All directional antenna CSMA related works are based on the same logic protocol: RTS and CTS transmission to inform neighbours and thus resolve the hidden node problem and blocking directional antennas towards area of communications (steering nulls). In [17], the authors propose the use of directional RTS and omnidirectional RTS. Directional RTS messages resolve the exposed node problem but collision may occur between acknowledgments and new RTS. For this reason, omnidirectional RTS messages are added to mitigate this problem.

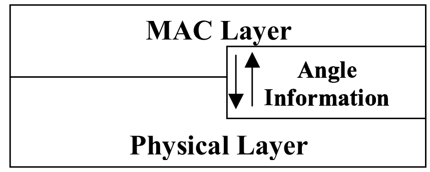

Figure 2: A Smart Antenna MAC Protocol

3 Problem analysis

We assume the use of a CSMA protocol at the MAC layer and a smart antenna within each terminal of an ad hoc network. An active signalling can be added to the CSMA protocol as it is specified in the HIPERLAN standard [18]. We assume also use of acknowledgments. Let N_s be the number of antenna elements within the smart antenna and N_{BM} the number of beamforming modules. When there are a number of simultaneous transmissions, a terminal attempts to receive up to N_{BM} packets simultaneously by forming multiple antenna beam patterns. Each module is capable of directing a beam at a desired packet. Each node is then capable of receiving at maximum N_{BM} packets at the same time. It is to note that this is a model for switched beam antennas as for adaptive array antennas.

Our objective is to add a sub-layer between the CSMA layer and the physical layer. This new layer has the job of optimizing the smart antenna CSMA protocol on the base of the information provided by the physical layer (see figure 2).

First, we resume the provided physical information to the MAC layer. Then, we give some remarks related to symmetry assumption in MAC protocols. At the end of this section, we explain two principal problems that have to be resolved by the physical information: Angle Selection and Handoff.

- Each node has to know the direction in which it can communicate with a neighbour. With this information, it is able to well choose the angle or the beam to ensure this communication. This information can be provided by an underlying proactive or reactive protocol. In the first case, control packets maintain within each node information on its neighbours (angle with maximum power [19], location [17]: GPS). In the second case, this information is provided in an on demand manner:

a one hop broadcast packet is sent to ask for the location or the maximum power angle. This demand can be implicitly included in a RTS packet and answered in a CTS packet as it is done in [17]. As in the case of routing protocols, in some scenarios, proactive protocols perform better and in other scenarios, reactive protocols perform better.

- Each node has to know about the current communications in the shared neighbourhood to not disturb them and to steering nulls towards their direction. In fact, with smart antennas, two communications may exist between nodes sharing the same "omnidirectional medium". Smart antennas reduce the communication zone and thus the coexistence of communications sharing some neighbourhood is possible.

It is to note that this information will be provided by the introduction of control packets between neighbours. In fact, it is clear that using smart antennas will be followed by an added overhead to make it possible each node to select transmission angle. Other control packets have to be used to make nodes aware about the neighbour communications. The question raised is if we have to keep the use of RTS/CTS to resolve the hidden node problem and if we can use them to provide the information needed to choose communication direction. Compared to omnidirectional antennas, with smart antennas, control packets can be used in directional or omnidirectional mode.

Another problem we think is worthy consists of the symmetry assumption adopted by most of related MAC protocols.

- Most of related protocols are based on the symmetry assumption. If a transmitter sends a RTS, it avoids its neighbours hearing this RTS use the shared medium, but its neighbours that have unidirectional links with it can send packets to it since they can not hear the RTS packet. The same remark is valid for CTS. A simulation study based on realistic propagation models (bidirectional and unidirectional links form the network) can evaluate the influence of such assumption on the performances of the MAC protocol in real ad hoc networks.

- Most of previous work assumed that two nodes communicating together are in Line Of Sight (LOS) of each other [15, 17]. In this case, GPS is useful to know transmission angle since we assume the existence of a LOS path between communicating nodes. This is not usually true if we take into account the presence of asymmetric links and unidirectional links.

The main problems discussed in this paper are: How efficiently a transmitter selects its transmission angle and changes it to mitigate mobility and propagation variation? We call both problems Angle Selection and Angle Handoff. We discuss in the next paragraphs these problems.

3.1 Angle Selection

The angle in which, a node A can communicate with a node B generally depends on reception power or precisely Signal to Interference and Noise Ratio $SINR$ (the required $SINR$ bandied is about $17 - 18dB$ [10] in case of voice transmission). Another criterium has to be taken into account: minimization of the frequency at which the transmission angle is changed or handoff (more details are in the next paragraph). For example, if the minimum aperture the antenna uses to transmit is $30°$, a node can send within only an angle of $30°$ or within two adjacent angles, each of $30°$. It can also use more than one angle that are not adjacents and within which the transmission is the best. At maximum, A can use $360°$ transmission angle as it uses an omnidirectional antenna. In this last case, no Handoff is needed. Optimizing the transmission angle needs a knowledge of node mobility relatively to its peer with which it communicates. If the node has no information about its mobility relatively to its peer, a periodic power sensing has to be done to adjust the transmission angle.

3.2 Angle Handoff

In our context, Handoff is concerned with updating the direction in which a node is transmitting. This update is necessary since smart antenna use is more sensitive to node moving than omnidirectional antenna use. With omnidirectional antennas, the only node movement influencing on a communication is related to propagation change or node moving away from its communicating peer. With smart antennas, a node can move but keeping the same distance from its peer. Both nodes may have to change the directions used to keep contact each one with each other.

Due to mobility, transmission angle has to be adjusted. This adjustment is based on power sensing. If A and B communicate, each one can be a transmitter and a receiver during the communication session.

Adjustment has to be done only by the transmitter node since adjustment within the receiver is automatic in case of switched beam and adaptive arrays antennas: all antenna elements are used for reception.

We present three approaches. The first is based on link state information to make it possible each node to benefit from its complete neighbour view. This information optimizes bandwidth used by nodes. This approach is designed for sparse networks since it needs high overhead use to get neighbour information. In case of dense networks, overhead increasing may decrease the throughput due to collisions. Previous works are based on the power criterium to choose the direction of a communication. We introduce a new criterium which is minimization of the number of disturbed nodes. The basic idea of our first approach is to adjust the communication zone (zone size which is dependent on transmission power and zone direction which is dependent on transmission angle). This adjustment maximizes the number of potential simultaneous communications, i.e., we tend to set the communication parameters that minimize the number of zones that can not be exploited by other nodes.

The second approach is designed for symmetric link networks. It is based on the following assumption: communicating nodes are in line of sight of each other. Finally, the third approach is designed for non symmetric link networks. It is more complicated than the second since more overhead is introduced to make more precise transmission Angle Selection and Handoff.

We go into details of the three approaches. At the end,

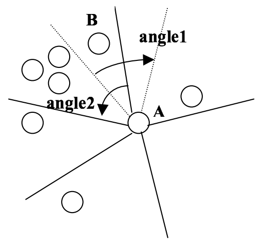

Figure 3: Optimization of the transmission angle: transmission within the angle1 is better than transmission within angle2

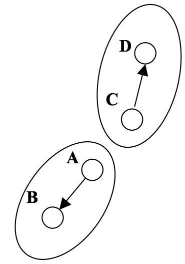

Figure 4: Exposed Node Problem

we give our conclusion and future work.

4 FIRST APPROACH: LINK SATE APPROACH

This approach is based on the following assumption: each node has a steerable antenna making it possible transmitting/receiving and steering nulls in specific angles. Each node knows for each angle (for example 0°,30°,.. ,360°), the corresponding reception power within each one of its neighbours. A previous work [19] proposes to allot for each communication the angle within which the reception power is the maximum. We think that this choice can not usually optimize bandwidth utilization. In fact, we think a communication can be set within a specific angle by making a tradeoff between maximizing the life of the link and decreasing interference. The first criterium can be tuned by the transmitter power or the transmission angle or both. The second criterium can be measured by the number of nodes that are disturbed by a communication. In fact, our idea is to focus the communication range in a zone where the potential number of disturbed persons is minimized and the stability of the link is kept (see figure 3). Although, decreasing the received power has also its disadvantages: link loss and handoff are more frequent.

The challenge is how to choose the function that makes the tradeoff between both criteria. Surely, this function will be strongly dependent on the topology: if nodes are not uniformly distributed, our function has to choose a transmission angle within which the number of disturbed persons is not too big. If nodes are uniformly distributed, our function coincides with the function maximizing the reception power. We explain in the next paragraph how in this approach, transmission Angle Selection, the hidden node and the exposed node problems are resolved.

The underlying overhead added to the CSMA MAC layer can be proactive or reactive as we mentioned in the preceding section. This overhead will provide information to resolve MAC protocol problems.

Each node sends (proactively or reactively) a control message to request information about the received power within neighbours. This request, containing the transmission angle, is sent sequentially within each angle. Each neighbour, receiving this request, replies with one control message containing the reception power within all angles. Each node has thus a complete information on its neighbours: for each angle, the corresponding reception power. Thus, it knows, for each angle, the number of potential disturbed neighbours. We can assume that a node is disturbed if the reception power is above a specified threshold.

4.1 Angle Selection

Concerning Angle Selection, we can notice that tuning the transmission angle is a kind of power control. This control concerns the power at the receiver and not within the transmitter. Tuning the power at the transmitter can also optimize the zone of communication of two nodes as it is done in cellular networks as GSM. Thus, taking into account power control at the transmitting node and the received power within the receiver and neighbours make more difficult the challenge to realize.

To resume, the main problem concerned with Angle Selection is how to choose a function that optimizes the communication zone within which two nodes can communicate without disturbing a huge number of neighbours. This zone, determined by transmission power and transmission angle, depends strongly on the topology. The simplest function we propose is to choose the angle within which the reception power is above a specified threshold and the number of disturbed neighbours is the minimum. The optimization of this function is a subject of our current research.

4.2 Exposed Node Problem

We keep the use of omnidirectional RTS/CTS messages to resolve the hidden node problem. Even though, we propose few modifications: the first modification optimizes broadcast transmission and the second modification resolves the exposed node problem. In fact, with classic RTS/CTS, neighbours block their communications until current communications finish which raises actually the exposed node problem. With the first modification, the omnidirectional RTS/CTS is sent only within angles where there are neighbours, it is not necessary to use angles not serving actual neighbours. This will save the transmission power. Concerning the exposed node problem, we propose that each node which is a neighbour of current communicating nodes, tests if it can set a communication without disturbing and disturbed by current communications. This means, communications have not to overlap. Suppose, A and B are communicating (see figure 4), C wants to talk with D. Two assumptions are possible: symmetry assumption and no symmetry assumption. In the case of the symmetry assumption, C/D and A/B communications do not overlap if C/A and C/D do not overlap, C/B and C/D do not overlap, D/A and D/C do not overlap, D/B and D/C do not overlap. This information is provided to C and D since they save link state information. C sends thus a RTS within all angles serving actual neighbours except those serving current communicating nodes (A and B) as it is proposed in [17, 19]. This node (C) has to steer nulls within unused angles for RTS transmission, .i.e. within A and B. This will save it from the potential disturbing by nodes unaware of its communication. We note that D, i.e. the node transmitting the CTS, will proceed with the same manner. Here, the symmetry assumption is used when supposing that C and D will not be disturbed by A and B since they steer nulls towards A and B. This is not usually true if links are not bidirectional.

In the no symmetry assumption case, there are other constraints. This time, steering nulls towards A and B can be insufficient: for example, A/B transmission angle can serve C even if C steers nulls towards A. For this reason, we propose, when each communicating node sends in its RTS/CTS, the neighbours detect angles within which, the reception can be a potential disturbing factor. This information has to be saved and updated. In our example, C and D save the reception angles from A and B. With these assumptions, C sends a RTS within all angles except those serving current communicating nodes (A and B) as is the case of symmetry assumption. The difference is concerned with steering nulls which is pointed to unused angles for RTS/CTS and also to angles within which RTS/CTS of A/B communications are received.

4.3 Angle Handoff

In this approach, handoff is not necessary if the underlying protocol providing angle information is proactive. Contrarily, if it is reactive, handoff has to be achieved on the base of power sensing or in the case of packet loss. The handoff will consist of control message retransmission to get information on new transmission angle candidates.

5 BEACON BASED APPROACHES

The Link State approach is not suitable for dense networks since it is based on a huge amount of control packets. Collisions may dramatically decrease the throughput in dense networks. For this reason, we propose the next tow approaches: symmetric link approach and polling approach. Both share omnidirectional beacon use to resolve the hidden node problem and directional data packet transmission. In fact, our idea is to keep use of RTS and CTS but as beacons since they are shorter and will not decrease the throughput performance. They are sent in omnidirectional mode to avoid potential collisions within the hidden node.

The difference between both approaches is principally concerned with Angle Selection, Angle Handoff and how the exposed node problem is resolved. Before going into details of both approaches, we explain their common basic control packets and used structure.

5.1 Control messages

As we mentioned, beacons are used as control messages between communicating nodes. To make it possible to each node to recognize itself as a destination, we propose the use of a specific beacon period for each pair of communicating nodes. Thus, we propose the use of classic explicit RTS/CTS messages to allow two communicating nodes agree on a specific value. These messages are sent in an on demand manner, i.e. if a transmitter A doesn't have the value of A/B control beacon period, it uses RTS/CTS messages to obtain it. Thus, these messages are not as frequent as in the case of the standard IEEE 802.11.

A node A that has data to transmit to a node B, sends an $ORTSB$ (Omnidirectional Request To Send Beacon): a beacon which long is already specified by A and B. This will mitigate the need of explicit control packets to ask for send or to authorize to send. By this way, each node can recognize the source of beacon without any packet processing. If A doesn't have information about the beacon period it has to use, it selects a random number to be the period of the control beacon for A/B communication and sends an $ORTS$ (Omnidirectional Request To Send) containing this information. B will reply by an $OCTS$ (Omnidirectional Clear To Send) confirming the A/B communication control beacon period. If B receives the $ORTSB$, it replies by an $OCTSB$ (Omnidirectional Clear To Send Beacon) to inform A that it is ready to receive. Actually, the $OCTSB$ is the same as the $ORTB$, but we use different notations to distinct their roles. In fact, when receiving the beacon, B knows that it is an $ORTSB$ since it didn't send an $ORTSB$. A also recognizes that the beacon it receives is an $OCTSB$ since it sent an $ORTSB$. Collisions may occur if A and B send at the same time the same beacon to request to send. We assume that this case is not probable since CSMA resolves the access to the channel.

5.2 Structure

Each node keeps:

- A table `Sector_Neighbour` containing for each neighbour, the possible transmission beams and their lifetime, the beacon interval and its lifetime. It contains also the other beacon periods used to communicate with other nodes. This last information is obtained through the periodic RTS and CTS packets. The table contains also the information on current communicating neighbours. This information is obtained through $ORTSB$ and $OCTSB$.
- The node/nodes for which it waits a packet unless it is in idle state.

5.3 Second approach: Symmetric Link Approach

5.3.1 Angle Selection

In this approach, if A has data to send to B, it sends an $ORTSB$ beacon in an omnidirectional mode. B will reply by an $OCTSB$ beacon in an omnidirectional mode. This $OCTSB$ will inform A about the transmission angle for A/B communication. In fact we consider that links are symmetric, thus the best reception angle is a suitable transmission angle candidate. The transmission angle depends on the underlying smart antenna: if a switched beam antenna is used, the reception is done within the beam with the maximum power, thus the transmission beam will be the reception beam. If an adaptive array smart antenna is used, the choice of the transmission angle is not obvious. In fact, the DSP in an adaptive array antenna adjusts the coefficients corresponding to the different antenna elements to decrease the effect of interfering signals. Radio links can be symmetric but received signal level at the receiver has no reasons to be symmetric with signal level at the transmitter. For this reason, we propose the use of the beam with the maximum power for transmission as we propose for switched beam antennas. Optimization of the transmission beam choice on the base of coefficient adjustment as it is done for reception is a subject of current research.

5.3.2 Exposed Node Problem

All the neighbours hearing the A/B control beacon ($ORTSB$ or $OCTSB$) block only their communications with A and B. This means, they can initiate communications with other nodes if the potential angle transmission is different from those for communication with A and B. In fact, all neighbours save the information on potential transmission angle with A or B. This information is obtained through the control beacon. The reception angle of A' $ORTSB$ is the transmission angle to A and the reception angle of B' $OCTSB$ is the transmission angle to B. This information is saved in the table `Sector_Neighbour`. Then, if for example a node C wants to communicate with a node D (see figure 4) and A is exposed to C since it communicates with B, C sends an $ORTSB$. It is to note that we keep the transmission of control beacons in omnidirectional mode since collision of beacons with other packets is not probable. C can send data to D only if C/D transmission angle is different from C/A and C/B transmission angles. Also, D/C transmission angle has to be different from D/A and D/B transmission angles. As in the link state approach, steering nulls is achieved towards communicating nodes (A and B) since symmetry assumption is adopted: A and B will not disturb C and D. The exposed node problem is thus resolved.

5.3.3 Angle Handoff

Angle Handoff is not necessary in this approach since the transmission angle used is usually updated by the reception of the control beacon $OCTSB$.

5.4 Third approach: Polling Approach

This approach called polling approach is based on a polling mechanism for both transmission Angle Selection and Handoff. We use both modes: directional mode if one beam or a few beams is used (for data transmission or signalling transmission) and omnidirectional mode if all beams are used (for signalling transmission). As we mentioned at the beginning of this section, $ORTS$ and $OCTS$ are used to confirm the period of the communication control beacon and, $ORTSB$ and $OCTSB$ are used to resolve the hidden node problem. An added overhead is used to make it possible for a communicating node to well focus its transmission: in this approach, links or beams are not necessary bidirectional, we suppose the presence of asymmetric and unidirectional beams. The added overhead is motivated by a polling mechanism.

5.4.1 Angle Selection

The polling mechanism corresponds to send a beacon ($DRTSB$: Directional Request to Send Beacon) within one or more beams and to wait for an answer. If the receiver hears the polling beacon and can receive, it replies with a beacon ($OCTSB$: Omnidirectional Clear To Send Beacon). In this case, the transmitter knows that the polled beam is a candidate beam for transmission. We propose two approaches for this polling mechanism.

In the first approach, we call Dichotomy Polling, the transmitter node searches for the first angle or beam that makes it possible to it communicating with the receiver. It consists of dividing each candidate beam set in two subsets. The polling is tested only within one subset. If the node gets a polling answer, it will divide the candidate subset as done before. This process continues until reaching the knowledge of one candidate beam. Let $N_s = 2^{n_s}$ and T_p the propagation time. Thus, the polling time is equal to $2T_p n_s$.

In the second approach, we call Sequential Polling, the transmitter node looks for all possible transmission beams. Sequentially, it polls and waits within each beam and keeps the information on all candidate beams. Thus, the polling time is equal to $2T_p N_s$. The transmitter can use one or all possible beams. It is clear that increasing the number of transmission beams increases link quality and decreases the number of handoffs but decreases frequency reuse.

It is to note that the first approach is faster but less stable since handoff probability is higher. We remark that the polling time is around few microseconds.

5.4.2 Exposed Node Problem

We can notice that we do not use the same RTS/CTS handshaking since neighbours hearing $ORTSB$ or $OCTSB$ do not block their communication as it is the case in the second approach. Even though, communications with current communicating nodes have to be blocked. In the second approach, a neighbour obtains "forbidden" transmission angles through control beacons since we adopt the symmetry assumption. In the absence of this assumption, a neighbour can only initiate a new communication if it has information about transmission and also reception angles with current communicating nodes. The reception angles can simply be obtained through $ORTSB$ and $OCTSB$ messages, but the transmission angles can not be provided unless the neighbour saved this information in the table `Sector_Neighbour`. For this reason, a lifetime is attributed to the transmission angles with neighbours. Thus, the exposed node problem is partially resolved in this approach since the proposed solution is conditioned by the presence of certain information.

5.4.3 Angle Handoff

In this approach, Angle Selection is not triggered at each new data packet transmission contrarily to the symmetric link approach where the transmission angle is usually updated through the control beacon $OCTSB$. In fact, triggering the polling mechanism each time a node has data to send may dramatically influence on the throughput performance of the network. For this reason, we propose the introduction of a handoff mechanism allowing transmission angle updating in case of propagation change. The handoff can be triggered in case of packet loss or by power sensing. Handoff due to a loss of packets is a hard handoff. Power sensing handoff is soft since transmission angles are updated before potential loss of packets. Even though, the soft handoff is more time expensive since received signal power has to be continuously sensed and transmitted to the MAC layer. Both handoffs are similarly carried out: the polling mechanism is restarted to select new transmission angles.

6 Conclusion and future work

We presented our reflections on smart antenna use for CSMA protocols in Ad Hoc networks. We propose a Link State Approach that makes it possible optimizing bandwidth allocation for communications sharing the same medium. The Link State Information is helpful since it provides information on neighbours within each transmission angle which may optimize broadcast. It also provides signal level within each neighbour. This approach has the advantage to set the transmission angle on the base of two important criteria: signal level within the receiver and the number of disturbed persons. To mitigate the disadvantage of this approach concerning the huge amount of control packets, we propose two other approaches: the Symmetric Link Approach and the Polling Approach. Both approaches are based on beacon use for Angle Selection and Handoff problems. Beacon use with an allocation of a specified control beacon period for each communicating node pair, saves us from use of explicit RTS/CTS messages for each data packet. The Symmetric Link Approach is simpler but based on the link symmetry assumption.

To resume: first, the control beacons are used in an omnidirectional mode to resolve the hidden node problem. Second, directional beams are used to optimize transmission Angle Selection through the polling mechanism. Third, the exposed node problem is resolved on the base of information about transmission and reception angles for current communicating nodes. We are working on simulating these approaches using opnet simulator. We are studying performance comparison between a MAC protocol with omnidirectional antennas and a MAC protocol with smart antennas. The major criterium we expect to optimize is the bandwidth utilization.

References

[1] V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LANs," in *Proceedings, 1994 SIGCOMM Conference*, London, UK, 31st - 2nd 1994, pp. 212–225.

[2] Chane L. Fullmer and J. J. Garcia-Luna-Aceves, "Floor Acquisition Multiple Access (FAMA) for Packet-Radio Networks," in *SIGCOMM*, 1995, pp. 262–273.

[3] Rodrigo Garces and J. J. Garcia-Luna-Aceves, "Collision Avoidance and Resolution Multiple Access for Multichannel Wireless Networks," in *INFOCOM*, Tel-Aviv, Israel, 2000, pp. 595–602.

[4] Z. Tang and J. Garcia-Luna-Aceves, "Hop-Reservation Multiple Access (HRMA) for Ad-Hoc Networks," in *INFOCOM*, New York, USA, 1999.

[5] F. Talucci, M. Gerla, and L. Fratta, "MACABI (MACA By Invitation): A Receiver Oriented Access Protocol for Wireless Multiple Networks," in *PIMRC*, Helsinki, Finland, September 1997.

[6] A. Tzamaloukas and J.J. Garcia-Luna-Aceves, "Poll-before-Data Multiple Access," in *Proceedings, IEEE ICC Conference*, Vancouver, Canada, June 1999.

[7] Z. Haas and J. Deng, "Dual Busy Tone Multiple Access (DBTMA) - Performance Evaluation," 1999.

[8] F.A Topagi and L. Kleinrock, "Packet Switching in Radio Channels: Part II – The Hidden Terminal Problem in Carrier Sense Multiple-Access and the Busy-Tone Solution," *IEEE Transactions On Communications*, vol. COM-23,no. 12, pp. 1417–1433, 1975.

[9] International Engineering Consortium, "Smart Antenna Systems," http://www.iec.og.

[10] Bruno Pattan, *Robust Modulation Methods and Smart Antennas in Wireless communications*, Prentice hall edition, 1999.

[11] Vytas Kezys Faisal Shad, Terence D. Todd and John Litva, "Dynamic Slot Allocation (DSA) in Indoor SDMA/TDMA Using a Smart Antenna Basestation ," *IEEE Transactions On Networking*, vol. 9, pp. 69–81, february 2001.

[12] Charbel Sakr and Terence D. Todd, "Carrier-Sense Protocols for Packet-Switched Smart Antenna Basestations," in *International Conference on Network Protocols (ICNP)*, Atlanta, USA, 1997.

[13] James Ward and R.T. Compton, "Improving the Performance of a Slotted ALOHA Packet Radio Network with an Adaptive Array," *IEEE Transactions On Communications*, vol. 40, pp. 292–300, 1992.

[14] James Ward and R.T. Compton, "High Throughput Slotted ALOHA Packet Radio Networks with Adaptive Arrays," *IEEE Transactions On Communications*, vol. 41, pp. 460–469, 1993.

[15] Martin Horneffer and Dieter Plassmann, "Directed Antennas in the Mobile Broadband System," in *INFOCOM*, San Francisco, CA, USA, 1996.

[16] A. Nasipuri, S. Ye, J. You, and R. E. Hiromoto, "A MAC Protocol For Mobile Ad Hoc Networks Using Directional Antennas," in *WCNC*, Chicago, September 2000.

[17] Nitin H. Vaidya Young-Bae Ko, V. Shankarkumar, "Medium Access Control Protocols Using Directional Antennas in Ad Hoc Networks," in *INFOCOM*, Tel-Aviv, Israel, 2000.

[18] ETSI STC-RES10 Commitee, "Radio Equipment and Systems: High Performance Radio Local Area Network Type 1," Functional Specification, June 1996.

[19] S. Bandyopadhyay, K. Hasuike, S. Horisawa, Y. Kado, and S. Tawara, "An Adaptive MAC Protocol for Wireless Ad Hoc Community Network Using Electronically steerable Passive Array Radiator Antenna," in *SAWN*, San Antonio, Texas, USA, November 2001.