Conception of a Relay Capable Multi-Mode MAC Protocol

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Abstract— **In recent years the wireless communication has increased rapidly. The main reason for this development is the steadily increasing demand for speech services. For the future it is expected that various types of data services will arise and that the demand for data services will be much higher than for speech services. These data services will require a ubiquitous mobile radio system with high data rates. This can be realised by a network deployment with a relative high density of Base Stations. But this is economically not reasonable, since the costs for connecting Base Stations to the fixed core network would be immense. Hence, to realise a cost effective ubiquitous mobile radio system, an extension of the coverage area of a Base Station is necessary. This can be achieved by using Relay Nodes which serve as Base Stations for User Terminals which are out of the coverage area of a Base Station and which are not wired connected to the fixed network, but wireless via a Base Station. User Terminals and Relay Nodes will have to face different environments, e.g. Line of Sight vs. Non-Line of Sight channel conditions or short-range/low-mobility vs. wide-area/high mobility. To facilitate a system that suits such a variety of scenarios, this paper proposes a multi-mode protocol which supports different modes for the different arising communication environments. For short range communication this is the Time Division Duplex-mode and for the wide area communication it is the Frequency Division Duplex-mode.**

Index Terms — **Multi-Mode Protocol, Relay, FDD, TDD**

I. INTRODUCTION

FUTURE mobile radio networks will have the requirement of very high data rates. Typical wireless data communication will not only occur in short range scenarios like hotspots in airports, city centres, exhibition halls, etc., but also in wide area environments, e.g. a moving car in a rural environment. Second-generation (2G) systems like Global System for Mobile Communications (GSM) offer speech and limited data services in wide area communication. GSM cells can have a radius of up to 35 km [1]. Unfortunately the data rates are rather low. Third-generation (3G) systems like Universal Mobile Telecommunication System (UMTS) provide higher data rates, theoretically up to 2 MBit/s. But this will not be sufficient for the needs of future data services like high-quality video streaming and telephony. Today's Wireless Local Area Networks (WLAN) like IEEE 802.11 a/g provide data rates of up to 54 MBit/s. The drawback of these systems is that they only have a very limited coverage area of up to a few hundred meters assuming very good channel propagation conditions like Line of Sight (LOS). Furthermore due to the Collision Avoidance (CA) mechanism they can only serve a limited number of users, so that they are only suitable for hotspots. This is strengthened by the fact that these systems do not provide a network architecture suitable to support user mobility.

Beyond Third-Generation (B3G) and Fourth-Generation (4G) mobile radio systems must therefore be able to provide high data rates both in short range and in wide area communication. Thus they must be capable of adapting to different communication environments. Furthermore, the usage of Relay Nodes (RN) must be supported in order to enlarge the coverage area of a Base Station (BS) in a way that the deployment costs of the network are reasonable low [2]. The ability to adapt to different environments can be provided by a Multi-Mode protocol [3]. Of course, this protocol must integrate the usage of RNs.

In Section II a brief description of the Multi-Mode Protocol concept is given. Section III describes candidates for different modes of such a protocol whereby the focus here is on the Medium Access Control (MAC) layer. Before concluding the paper the principal layout of the frame structure of the MAC protocol is shown in Section IV.

II. MULTI-MODE PROTOCOL CONCEPT

The Multi-Mode Protocol Reference Architecture, as proposed in [3] provides a framework for the efficient realization of multi-mode capable protocols. The reference architecture describes a protocol stack of a flexible, dynamic reconfigurable air interface for future wireless networks. The multi-mode protocol controls one single adaptive system for all envisaged radio environments which can efficiently adapt to multiple scenarios by using different modes of a common technology basis. Fig. 1 shows the reference model. The underlying assumption of the reference model for multi-mode protocols is the separation of the functionality of a protocol layer into mode-specific parts and generic parts. Generic parts are functionalities which are common to all modes. They do not complete the full functionality of the protocol layer, not to mention a full protocol stack. The completion is achieved by the mode specific functionalities. As illustrated in Fig. 1, the full functionality of a protocol layer is achieved through

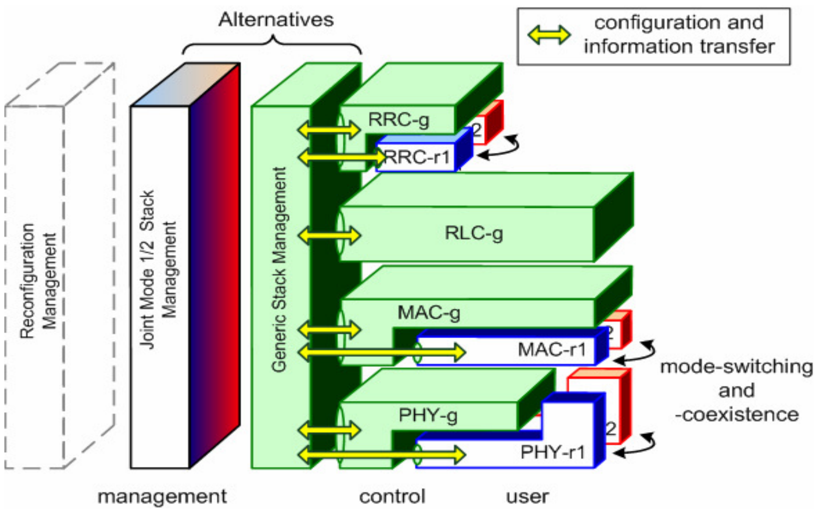

Fig. 1 Reconfigurable Multi-Mode Protocol Reference Model (Source: [3])

composition from generic and the mode-specific functions. This composition can be changed at run-time to implement a change of the behaviour of the protocol stack from one mode to another. Generic parts of a (sub-)layer are depicted with X-g where X stands for the (sub-)layers Radio Resource Control (RRC), Radio Link Control (RLC), MAC and Physical (PHY) layer. Specific parts are denoted X-r_i with $i \in [1, N_X]$, N_X number of modes in (sub-)layer X.

In [4] it is described how such a dynamic reconfigurable protocol stack can be realised. According to [4] the Data Link Layer (DLL) protocol stack of a wireless communication system consists of several functions. These are Segmentation and Reassembly (SAR), Automatic Repeat Request (ARQ), scheduling, multiplexing, and buffering. In [5] these functions are called Functional Units (FU) and can be dynamically composed to a Functional Unit Network (FUN) during runtime representing one layer of a protocol stack.

In order to enable such a dynamic protocol stack, the used protocols must be analysed and functions of a protocol have to be identified for being represented by FUs.

In this paper we focus on the multi-mode aspects of a relay capable MAC protocol. Fig. 2 shows the structure of the user data plane of a reconfigurable DLL protocol stack which is built up in the above described way. In this example the RLC sub-layer consists of the FUs SAR and ARQ. The generic part of the MAC sublayer consists of FUs scheduling, multiplexing and buffering. In this paper the focus is on the ability of a MAC protocol to handle different modes. The investigated modes are the ones depicted in Fig. 2, namely the duplex schemes Frequency Division Duplex (FDD) and Time Division Duplex (TDD). This approach differs from the one introduced in [6] by its ability to be configured out of several components and to exchange these components during runtime. In [6] different MAC layers as a whole are considered allowing the dynamic exchange of the whole MAC protocol.

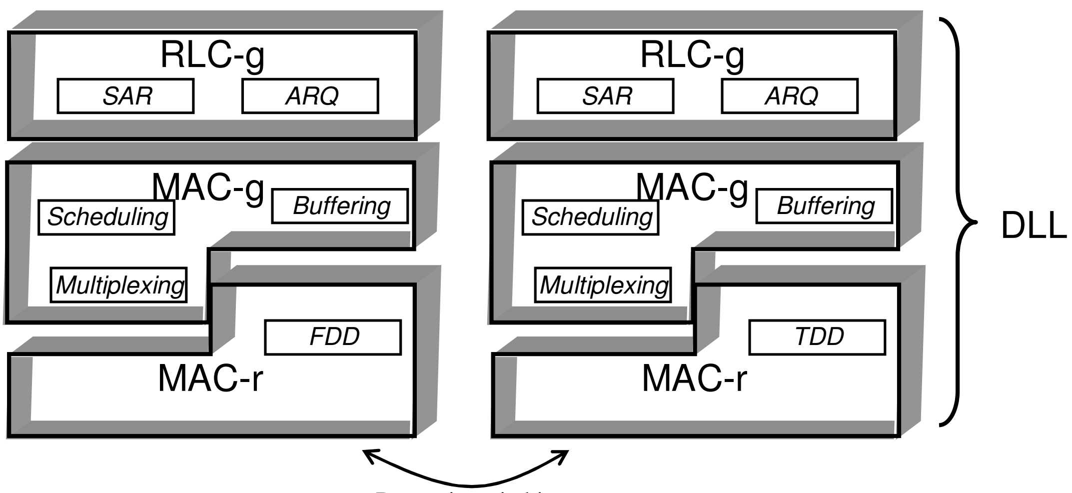

Fig. 2 Data Link Layer (User Plane) - Dynamic reconfigurable protocol stack in FDD- and TDD-Mode

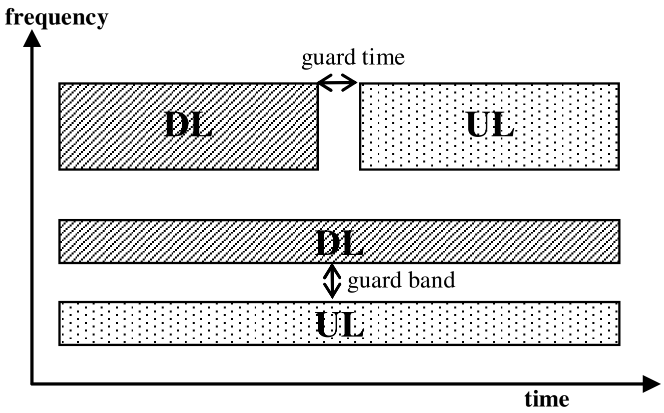

Fig. 3 Frequency and time plan of the two duplex schemes

The parameterisation is specific to the respective MAC layer whereas in our approach the parameterisation itself provides the composition of the protocol stack.

III. DUPLEX SCHEMES

In communication systems two kinds of communication directions are distinguished, namely the direction towards (UL, Uplink) and from (DL, Downlink) the core network. In mobile radio systems the connection to the core network is normally given by the BS. Thus the BS originated communication is called DL and the BS aimed communication is called UL. There are two ways how the two communication directions can be handled. These two methods are the duplex schemes TDD and FDD. Fig. 3 shows the general structure of the two methods. In TDD for DL and UL communication the same radio resource is used alternating over time. In FDD two different radio resources are available for the two directions, so that DL and UL communication can occur at the same time.

Due to the switching between DL and UL phases in TDD a guard time between the two phases is necessary, in order not to suffer from interference between the transmissions of the two phases which can occur due to propagation delay. The larger the cells, the larger possible communication distances can be and the larger the guard time has to be in order to avoid above mentioned interferences. Larger guard times unfortunately degrade transmission efficiency, since the guard time cannot be used for transmission. Furthermore, large guard times can lead to non-compliance with delay and response time constraints. As the guard time grows with the cell size, delay and response time constraints directly lead to cell size constraints in systems using TDD. FDD does not suffer from this problem, since it uses two different radio resources for DL and UL. Consequently no guard time is necessary. A disadvantage of FDD is the missing flexibility offered by TDD. A lot of data services exhibit a high asymmetry between UL and DL traffic. This can be considered in TDD systems by adaptation of UL and DL times. FDD does not provide this flexibility, because adapting the spectrum used for UL and DL transmission respectively is typically not an option.

IV. DUPLEX SCHEMES AS MODES

When considering the properties of the two duplex schemes, TDD – due to its flexibility – is applicable for both symmetric and asymmetric traffic, but only up to a certain cell size. In order to support larger cell sizes at given delay constraints FDD is the favourable option. Generally it can be said that TDD is more adequate for short range communication [7] occurring in hotspot environments like airports, city centres, exhibition halls, etc. and FDD more adequate for wide area communication [7] which can be found in more rural environments where the user density is lower than in urban environments which consequently leads to a lower BS density and to larger cell sizes.

Current Radio Access Technologies (RAT) are either TDD or FDD based, but none of them uses both schemes. GSM is an FDD system [1]. The Universal Mobile Telecommunications System (UMTS) has two RATs, UMTS Terrestrial Radio Access (UTRA) -TDD and UTRA-FDD [8, 9]. At first sight this seems to be a system facilitating both duplex schemes. But de facto currently only UTRA-FDD is in use and there are no User Equipments (UE) which are able to handle both schemes. All IEEE 802.11 based standards are TDD only systems [10]. A currently upcoming system providing both schemes is Worldwide Interoperability for Microwave Access (WiMAX) [11]. However, it does not aim to provide a dynamic switching between the schemes as an adaptation to the communication environment.

As motivated in Sections I and II, a MAC protocol for a B3G system should be able to integrate the usage of RNs which extend the coverage area of a BS wirelessly and so do

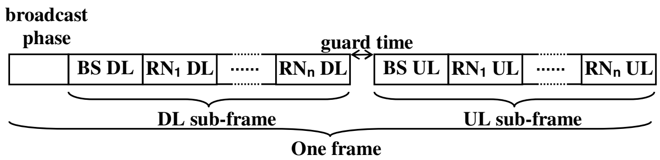

Fig. 4a MAC frame structure in TDD mode with RNs

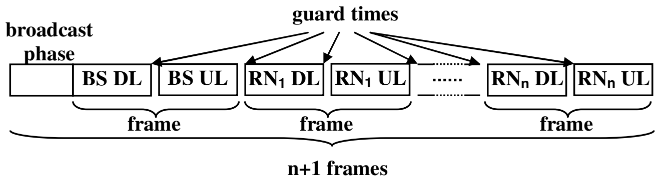

Fig. 4b Aggregated MAC frame structure in TDD mode with RNs

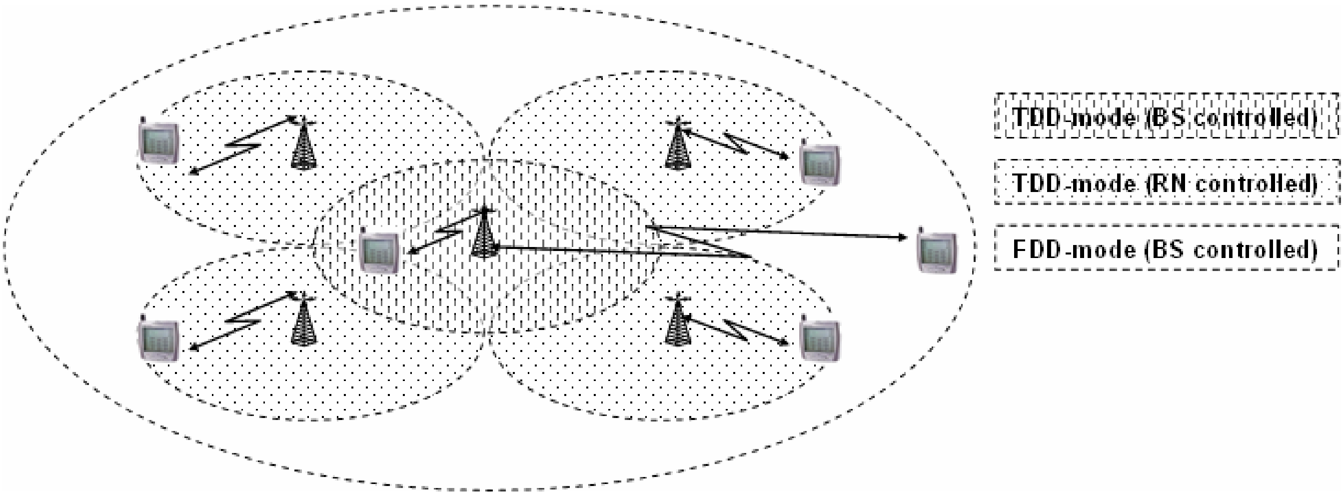

Fig. 5 Exemplary scenario with one BS and four RNs using TDD-mode in short range and FDD-mode in wide area communication

not have as high installation costs as BSs. In order to support the communication in different environments the MAC protocol should also be multi-mode capable with one mode for short range and one mode for wide area communication, namely TDD- and FDD-mode. Fig. 4a shows a possibility to integrate the usage of RNs into such a MAC protocol. The considered TDD MAC frame structure is composed of a broadcast phase where information about the cell is broadcasted, a DL sub-frame and an UL sub-frame. The integration of the RN usage is done by sharing the available resources among the BS and the RNs both in UL and DL. The information about the resource partitioning is either included in the broadcast phase or if the amount of information is too large to be sent during the broadcast phase it has to be sent during the BS DL phase. Assuming the BS and the RNs are synchronised, i.e. the frame start and end are at the same time, both the BS and the RNs send the information when their DL and UL phase in the according sub-frame will take place together with a preamble for the synchronisation of the User Terminals (UT) to the BS and RNs respectively in the broadcast phase. The order and length of the phases and the number of phases assigned to a RN during a sub-frame can be arbitrary and are out of the scope of this paper. For this kind of aspects cross-BS considerations have to be done. The Radio Resource Management (RRM) would be in charge of this issue and it is of interest for radio network planning considerations, because an intelligent order of the phases can avoid co-channel interference. If the information sent during the broadcast phase does not have to be updated every frame, it is possible to increase the efficiency of the protocol by omitting the broadcast phase. Again dependent on the amount of information the resource partitioning can be sent either during the broadcast or during the BS DL phase. Fig. 4b shows such an overlay frame structure. Having n RNs the broadcast phase recurs every n+1 frames. The frames in between are normal MAC frames except the broadcast phase. In the shown example the BS and each RN are assigned exactly one whole frame between consecutive broadcast phases. Of course, the number of frames does not have to be determined by the number of RNs in the cell. Furthermore, the assignment of resources does not have to rely on frame basis. The number of frames between two broadcast phases and the amount of resources assigned to the BS/RNs have to fulfil possibly given delay and response time constraints. But again this is an issue of the RRM. Here only the RN support of the MAC protocol is of interest.

Up to now only the integration of RNs into a TDD frame structure has been considered. As mentioned before the usage of RNs intends to extend the coverage area of a BS in a cost effective, namely wireless way. In order not to increase the costs of a RN, it should be as simple as possible. So, initially RNs should only support TDD. Moreover FDD is applicable for wide area communication. This implies that a BS can cover an area which goes over the coverage area of the BS and RNs controlled TDD cells. In Fig. 5 such a scenario is depicted. The BS's coverage area is extended by four RNs. Each of them as well as the BS is operating with TDD. Additionally the BS concurrently is operating in FDD at two other frequency bands, one for the DL and one for the UL. For the FDD operation the BS uses a higher transmission power in order to guarantee a larger coverage area. This is possible due to the applicability of FDD for wide area communication.

To be able to support such flexibility the MAC protocol has to provide two modes, one for FDD and one for TDD. Both the BS and the RNs have to inform the UTs about the used mode. This is done in the broadcast phase. The UT first tries to associate to the BS/RN whose preamble it receives with the highest signal strength. This happens using the TDD-mode. Whenever the UT does not detect any preamble with sufficiently high signal strength, which can also be the initial mode selection at switch-on of the UT, it checks if it is in the coverage area of a "wide area cell". Therefore it changes the used frequency and checks if it can detect a preamble which is sent on resources of the FDD DL band. Whether the change of the mode occurs seamlessly or not is again a task of the RRM. It is responsible for providing functionalities for measurement reports in order to be able to check for the availability of a BS/RN in another mode. Since the wide area cell encloses its appropriate short range cells, the change of the mode from FDD to TDD cannot proceed in the same way mode change from TDD to FDD does, because diminishing preamble strength is no indicator for mode change any more. Quite the contrary is the case. Increasing preamble signal strength indicates that the UT is moving towards a cell operating in TDD-mode. To be able to recognise an existing TDD cell, the UT either has to check the availability of short range cells by switching to the TDD frequency band periodically or the UT does the check according to experience values. These values could be the strength of the first received preambles directly after switching to FDD-mode, as the switching more or less occurs rightly at the end of the short range cells. So a received preamble strength close to the stored values could indicate approaching a TDD cell. A similar approach is pursued in [12] to shorten handoff times in IEEE 802.11 networks. Here Access Points (AP) inform their Stations (STA) about the beacon time and frequency channel of neighbouring APs so that the STAs can switch the used frequency channel at the right time in order to get information about handover possibilities.

V. Conclusion and Future Work

In this paper a concept for a relay based MAC protocol with integrated support for multiple modes is introduced. The proposed MAC protocol is able to support the usage of wireless connected RNs in order to extend the coverage area of a BS in a cost efficient way. Moreover the MAC protocol can adapt to different communication environments by its ability to operate both in Time- and Frequency Division Duplex modes.

Currently the introduced concept is being implemented into the structure described in [5]. The goal is to proof the proposed concept by means of simulations.

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