Switched Multi-Radio Transmission Diversity in Future Access Networks

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***Abstract*— Based on a novel extension of PHY-layer diversity mechanisms applied in today's wireless systems, Multi-Radio Transmission Diversity (MRTD) corresponds to a family of diversity schemes for deployment in emerging multi-radio access networks. In this paper we describe and evaluate, via simulations, the performance of Switched MRTD at MAC packet level and as applied to multiple radio accesses, each utilizing link-adaptation and TDMA reservation MAC protocols. Performance gains of the switched diversity scheme, in conjunction with multi-radio ARQ, are presented via throughput and delay statistics in typical indoor and urban environments.**

Keywords- multi-radio access, transmission diversity, multi-radio ARQ; communication systems beyond 3G; generic link layer

I. Introduction

The highly dynamic nature of the radio channel is undoubtedly the key source of degradation of quality of service in wireless communications. To mitigate the variable nature of the ether and to improve the quality of communication over fading radio channels, various diversity techniques have been developed in the past. Examples can be seen in practically all wireless systems. Temporal diversity is exploited in interleaving, encoding, time-domain equalization, rake processing and ARQ mechanisms. Frequency diversity is exploited in the design of wideband signals via direct-sequence spreading, frequency hopping, multi-carrier modulation and impulse radio. Spatial diversity is exploited in the form of hard and soft handoff amongst spatially distributed base stations. Spatial diversity is also exploited through the use of multiple antennas at either the transmitter, or receiver, or both.

Furthermore, the advent of multi-radio access (MRA) [1] [2] for next generation wireless systems will allow for the integration of different radio access technologies (RATs), where user service demands are efficiently mapped on to multiple "heterogeneous" radio access network at any instant of time [3]. An approach for the realization of such multi-radio environments is through unified or joint link-layer processing across different radio accesses. Such a Generic Link Layer [4] would enable the possibility of communication between wireless devices via a rich set of diverse radio accesses. Here the term "radio accesses" (RAs) is used to refer to uncoupled radio channels either across different radio access technologies (RATs) or within a single radio access technology.

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The objective in this paper is to explore the potential for performance improvements through *novel* extensions of the transmission diversity (TD) paradigm to joint link-layer processing in emerging multi-radio access environments.

II. Multi-Radio Transmission Diversity

Multi-Radio Transmission Diversity (MRTD) may be broadly defined as the dynamic selection of multiple radio accesses for the transmission of a user's data. This naturally assumes the availability of devices (e.g. infrastructure nodes and user mobiles) capable of transmission and reception over multiple RAs. MRTD principally consists of a multi-radio selection policy, which assigns a RA to each "scheduled" data-unit according to a set of RA quality metrics. Consequently, MRTD can be thought of as consisting of a packet scheduler operating across multiple radio interfaces. Depending on the exact nature of the multi-radio selection policy, various MRTD schemes are possible, as defined by the three attributes of: re-selection rate, parallelism and redundancy. The *re-selection rate* refers to the rate at which radio access selection is performed. This may correspond to the transmission time of data units ranging from a PHY- or MAC-layer PDU, to multiple IP packets, or even that of a complete data flow. Thus, depending on the re-selection rate, MRTD can be performed at different protocol levels (e.g. at MAC or IP level). *Parallelism* refers to the possibility of selecting one *or* multiple RAs at any given time for the transmission of a user's data, resulting in what we term switched (sequential) or parallel (simultaneous) MRTD respectively. *Redundancy* refers to the possibility of transmitting copies of the same data over multiple RAs (prior to any reception acknowledgements) as part of the TD mechanism. Different MRTD schemes may be envisaged through various combinations of the above attributes. In this paper, we focus on Switched MRTD of MAC-layer PDUs without the use of redundancy.

III. Switched Transmission Diversity at MAC Level

This scheme corresponds to a diversity algorithm whereby a user's data, equivalent in size to the payload of MAC-layer PDUs, is *transmitted* via one, and only one, RA PHY-layer at any given time. Successive MAC PDUs may be transmitted via different RA PHY layers, as directed by feedback from the RA protocol stacks. In one possible implementation of the multi-radio packet scheduler proposed here, a user's transmission data is processed in parallel by the RLC/MAC protocols of *M* RAs, but is transmitted via the PHY-layer of a single RA only. At any given time, the scheduler has effectively a choice of *M* modulation and coding schemes per user, conditioned on the perceived channel conditions of the *M* RAs. The scheduler services a user by selecting one of the *M* RAs, and transmitting the appropriate number of MAC PDUs, as identified by the associated modulation and coding scheme, within a PHY-layer transmission time interval. This is illustrated in Fig. 1 below for *M*=2 RAs supporting different bandwidths.

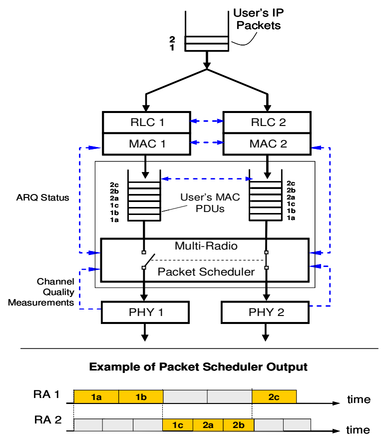

Figure 1. Re-selection at MAC PDU level for a user's traffic.

In this example, each RA-specific MAC layer segments each of a user's IP packets into three MAC PDUs. Each time the transmission of a PDU is complete, the scheduler forwards the next PDU to one of the two PHYs. The selection is based on an estimation of the channel conditions. In the above example, the underlying assumption is that MAC PDUs belonging to different RAs correspond to the same information bits. In practice, there will always be a mismatch between the MAC PDU payload sizes across multiple diverse RATs. In such cases, a *book-keeping* scheme is necessary in order to keep track of the information that is actually transmitted across the diverse RATs. Judicious adjustment of MAC PDU payload sizes can simplify the book-keeping process. Indeed, in most systems, the MAC PDU payload size is a variable parameter which can be adjusted within a specified range. Through such adjustment, and possibly zero-padding, the MAC payload sizes can be matched (at least to within convenient rational multiples).

The impact of multi-radio packet scheduling on the RA-specific ARQ mechanisms is of great significance. Successful reception of the transmitted data results in the receiver replying with an acknowledgement (ACK) transmitted via the same RA as the original data. Upon such positive acknowledgement, the successfully communicated MAC PDUs are removed from the buffers of all *M* RAs, and the scheduler proceeds to service the remaining packets. Should the transmitted MAC PDUs be received unsuccessfully, they may be re-transmitted via a new RA (dependent on the radio channel estimation) as determined by the scheduler. Such *multi-radio ARQ* mechanism can result in gains in throughput over that achieved by RA-specific ARQ, since the channel conditions in different RAs are typically independent.

IV. Simulation Model and Performance Evaluation

The gains achievable by performing switched MRTD at the MAC PDU level are evaluated here by means of simulation. The simulation scenario is based on a multi-radio access network consisting of base stations serving multi-radio mobiles via a number of independent radio accesses, as shown in Fig. 2. Downlink data for each mobile is transmitted on one, and only one, RA at any given time. Of course, a base station may indeed transmit simultaneously on multiple RAs, however the transmitted data would be associated with different mobiles. The infrastructure will have access to *regularly* updated metrics for driving the access selection process, such as the quality of the downlink channel for each mobile and each RA, and the traffic load on each RA. Some metrics are supplied by the mobiles via regular reports transmitted on the uplink of each RA. Others are inferred from measurements and observations (of the PHY, MAC, or RLC layers) made by the infrastructure itself.

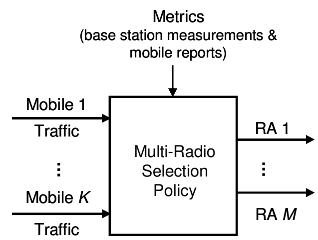

Figure 2. MRTD for the downlink.

The radio interface is modelled as a coded single-carrier PHY layer, subject to path-loss, shadowing, and multi-path fading. Adaptive modulation and coding (AMC) ensures that the transmission data rate in each RA matches the instantaneous channel conditions. A TDMA scheme, based on a reservation MAC protocol (e.g. HSDPA, 802.11 PCF) is also considered. The performance of MRTD and muli-radio ARQ in a multi-radio access scenario is benchmarked against an equivalent scenario where the RAs operate independently. Performance gains are measured in the form of throughput and delays statistics as a function of RA bandwidths and coverage areas, as well as measurement signalling delays.

References

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