How to Benefit from Cooperation in Latency-Constrained Wireless Communications

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***Abstract*—Future wireless systems must provide guarantees for high reliability and low latency to take account of the increasing demand in M2M communications. Cooperation is a simple and effective way to increase the reliability, even when bounded to short transmission deadlines and limited hardware features. On the local level, the access to the shared transmission medium may either be controlled in a centralized or in a decentralized way, while both options have their advantages and disadvantages. We show that for both of these options it is possible to effectively include cooperation in the MAC design, using the example of cooperative ARQ, and thus to benefit from spatial diversity.**

I. Motivation

An important challenge of future wireless communication systems is to support the emerging demand for Machine-to-Machine (M2M) communications, as it significantly differs from the hitherto application of wireless technology in home and business environments. In industrial automation, for example, wireless technology could contribute in increasing the production flexibility while also reducing the costs. However, a prerequisite to substitute the existing fieldbuses with wireless solutions is to guarantee the same high reliability and low latency as provided by cables. This is especially true when aiming at safety- and mission-critical applications, requiring strong guarantees in both domains to function as expected [2].

The reliability of wireless communication can be significantly increased by exploiting diversity schemes in frequency, time and space. Nevertheless, applying one of these schemes comes at a price and may even conflict with other design goals. Frequency diversity spreads the transmission signal over a wide spectrum or by using multiple sub-channels in parallel. Unfortunately, radio frequencies are a scarce resource, which must be shared by all stations in transmission range. Time diversity, on the other hand, aims at spreading the signal over time to increase the reliability. This contradicts the notion of aiming at low latency, especially when considering the coherence time of a wireless channel. As a third option, spatial diversity exploits uncorrelated transmission paths, e. g., by using multiple antennas at the transmitters and / or receivers. Due to cost and size limitations, multiple antennas are often not included in a single device. Alternatively, cooperative schemes form a virtual antenna array across stations, which exploits spatial diversity at the expense of timely dedicated retransmissions. Due to the broadcast nature of wireless transmissions, a third station may overhear the original transmission and retransmit the message if necessary.

In the following, we present two design options for local wireless communication cells, incorporating cooperation through cooperative Automatic Repeat reQuest (ARQ) [3] while aiming at ultra-high reliability, i. e., an error probablity of 10^{-7} or less, within ultra-low latencies of a few milliseconds.

II. Incorporating Cooperative ARQ

There are basically two ways of implementing the MAC, either *decentralized* or *centralized*. Both options may make use of cooperative ARQ, assuming that transmitter, receiver and a potential relay are all in communication range.

To establish strict time guarantees in a decentralized way, we propose a wireless toking passing scheme [1], in which the token deterministically grants medium access by rotating between the stations. Determining channel states comes at negligible cost as the frequently rotating token is used for channel estimation. Based on this information, a transmitter pro-actively selects a relay for message retransmission.

In the centralized option, a local base station (BS) is in charge of coordinating the communication, by assigning Time Division Multiple Access (TDMA) slots to the stations. A certain portion of the TDMA frame is reserved for retransmissions, which are centrally performed by the BS. Enabling the BS to cooperate reduces signaling overhead, allows to benefit from potentially more complex transmission schemes, and shortens the time reserved for cooperative ARQ since a retransmission multiplexing gain can be realized.

III. Conclusion & Future Work

Cooperative ARQ is an additional source of diversity, often not considered in the design of high reliable, low latency communications. It can be effectively integrated in decentralized and centralized topologies. For the decentralized option, we showed its reliability gain in [1]. For the centralized option, preliminary analytic results indicate a high reliability gain, we plan to confirm by simulations and real-word implementations.

References

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