The Implementation of Non-Coherent Cooperative Transmission for Wireless Sensor Networks

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Abstract. Traditional approaches using superimposed signals in wireless sensor networks have high demands on the hardware capabilities of a single network node. In this demo, a practical implementation of a non-coherent cooperative transmission system is showed in a real hardware implementation. For the feasibility and practical implementation an additional modification on the current theory in the literature was necessary. The demo shows how a group of sensor nodes can increase their transmit range by using simultaneous transmission to sum up their power as a group. To our knowledge, this is the world's first implementation of non-coherent cooperative transmission.

1 Introduction

In wireless sensor networks, the quality of the channels and links between stations are often poor due to environmental factors such as occlusion, reflective objects, mobility and low power transmission. Figure 1 shows the typical application for cooperative transmission that we want to discuss as our reference scenario for the demo. Multi-hop connected sensor nodes distributed in the wilderness want to transmit collected data to a destination like a stationary antenna tower, plane or satellite. The distance to the destination is too far, that a single node cannot communicate its data with sufficient SNR to the base station and there are no intermediate relays. This scenario has been previously named as the *sensor reach back problem* [1]. There are several arguments (e.g. the problem of a single point of failure) why a powerful up-link station among the sensor nodes is not expedient. We assume that time synchronization and random data exchange is possible between all pairs of nodes in the sensor network.

In this demo, we want to look at cooperative transmission under the constraint of very inexpensive sensor network nodes. The sensor nodes transmit identical symbols *simultaneously* over the radio channel to accumulate their energy and therewith increase the total transmit power. Here, we find two major differences in the literature: Firstly, *coherent cooperative transmission* where stations superimpose their signals to achieve coherent phase in the destination receiver ([2], [3]) and secondly, *non-coherent cooperative transmission* where the

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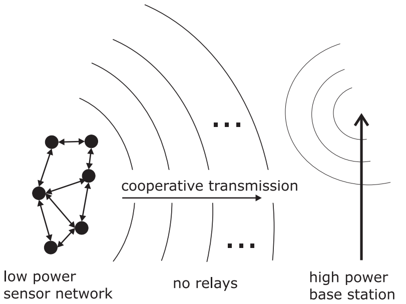

Fig. 1. The sensor reach back problem

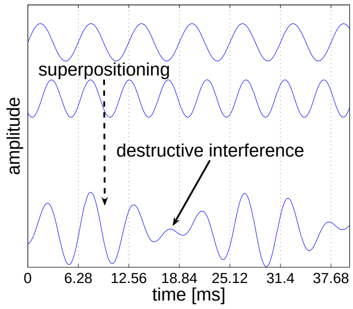

Fig. 2. Example signal interference from two stations emitting a radio wave. The superposition of the signals leads to time-varying interference patterns

station superimpose their signals without aligning their phases according to the receiver. For the ease of implementation and feasibility of the demo, we choose the latter one. Additional details and argumentation for this can be found in [4] and [5]. In this demo, we propose additional modifications to the theory due to the feasibility of the practical implementation. We also demonstrate the world's first implementation of non-coherent cooperative transmission on the particle computer [6] sensor nodes.

2 Non-Coherent Cooperative Transmission

When two or more stations emit a signal simultaneously to reach a higher total transmit power, the problem of interference occurs as a major drawback for the practical usage. Figure 2 shows such a situation. The waves emitted by the nodes superimpose on the radio and lead to periodic patterns of constructive and destructive interference. When the signals of the emitted signals are phase-aligned in the receiver, the summation of energy leads to a higher total transmit power whereas the destructive interference temporarily suppresses the positive effect of superimposed signals. For a practical implementation, it is necessary to avoid these destructive interference. Theoretically, it is impossible to fight these interferences in the receiver without monitoring the received signal for at least the length of the period of the interference pattern. The length of the period depends on the local oscillators' frequencies which cannot be globally controlled due to practical reasons. But when a symbol time is shorter than the period of the interference patterns — which will typically be the case — the observation of one symbol will be shorter than one interference period and the interference will therefore severely influence the overall performance.

Due to this shortcoming of the current theoretical approaches in the literature, it is necessary for a practical system, to prevent the interferences by using additional modification in the transmitter. Aligning the transmitters' phases has been proposed in [3] but is too complex for the implementation on sensor nodes. Instead, we propose the use of an additional signature on the emitted symbols to control and shorten the period of the interference pattern. In figure 3, different signatures are applied on the symbol to be transmitted. Two signals of 1ms duration are superimposed. Their carriers have a 100Hz differentiation, leading to an inteference period of 10ms, ten times higher than the actual symbol time (1ms). The figure shows the three cases of 1) perfect aligned phase, 2) pure superimposed signals, 3) a signature of 5kHz bandwidth, 4) an additional signature of 100kHz bandwidth. The powers of both transmitters are normalized to one, therefore, in the perfect aligned case, the received power of the sum of signals is ideally "2". For non-coherent superimposed signals without additional signature, the distribution of the received signal is useless due to the too short observation (1ms observation on the 10ms period). But with the additional signatures (in this case bandlimited noise), the distribution in the receiver can be controlled.

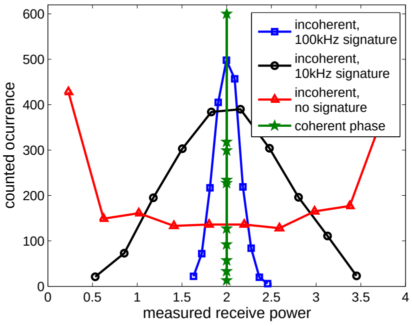

Fig. 3. The simulated distributions for coherent and non-coherent superimposed signals

3 Implementation

In the demo, we will show the principles of superimposed signals. Figure 4 shows the demo setup similar to the sensor reach back problem. Four transmitters will synchronize and superimpose their signals to reach the far receiver. The receiver will evaluate the received power and decide for a symbol or not. During the demo, it can be shown that one transmitter alone cannot emit enough power to reach the receiver. But, when more transmitters are used simultaneously, it is possible to sum up their transmit power. The demo shows the principle of the additive behavior of superimposed, non-coherent signals. Visitors of the demo can interact with the setup by turning on and off different transmitters. The receiver will online display the received power on a level meter and also display

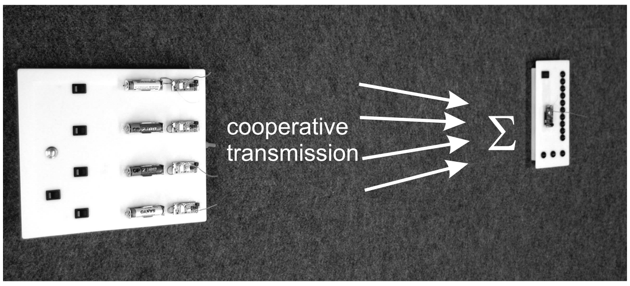

Fig. 4. The demo setup: four particle computer sensor nodes transmit cooperatively to one receiver

it's local decision on the reception and give the visitor a vivid impression of the superimposed signals. The demo works without additional laptops or external hardware. All signal processing is done exclusively on the nodes.

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