Weekly Report (2010-11-04)

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I. State of the Art about PNC

Since the born of physical-layer network coding by [1], [2], a bunch of exciting work have been conducted in this area. According to their focuses, these papers can be mainly divided into following categories:

- *Coding and Modulation Scheme:* This topic is the foundation of PNC, which addresses on how to encode-decode and modulate-demodulate on the physical layer. Different coding or modulation schemes may lead to different BER performance with the same SNR.
  - *Coherent Modulation:* Most of current work [3], [4], [6], [7] are on this aspect. For coherent modulation, we have a strong assumption that the source nodes, which may also be destination nodes in PNC, and the relay nodes have full and accurate information about the channel state including amplitude attenuation and phase-drift. This assumption may be valid in static network with slow-fading channel. However, in reality, complete channel state information is not available or not accurate enough in dynamic network or fast-fading channels.
  - *Noncoherent Modulation:* As a counterpart of coherent modulation, the encoding-decoding or modulation-demodulation of noncoherent modulation does not depend on the channel state information. Up to now, I find that differential modulation (DM) [5], [8], [9] is a popular choice in this domain since DM only cares about the difference between the wave-forms in current time slot and previous time slot. However, the BER performance is 3db higher (current best result [9]) than that by coherent modulation with the same SNR. Besides, as a cost of the lack of information, the algorithm complexity is increased.
- *Analysis:* The analysis for physical-layer network coding, e.g. network capacity, is rare in literature. This may be explained that the capacity of wireless networks even with a single source-destination pair is still unknown.
  - *Utility Optimization:* Rate optimization [14], power optimization [9] and constellation optimization [13] can be found in literature. Primal-dual decomposition and subgradient methods are commonly seen.
  - *Capacity Analysis:* In [15], the achievable capacity with analog network coding under high SNR is analyzed as I introduced in last report. Cut-set bound is utilized for comparison purpose.
  - *Scheduling Complexity:* Goussevskaia and Wattenhofer [12] explore the link scheduling complexity with physical-layer network coding under the SINR model. To me, this is just a simple extension of their previous works on scheduling complexity under the SINR model.
- *Application:* There are only a few papers exploiting the application of physical-layer network coding. To my understanding, this stems from the fact that current physical-layer network coding schemes, more or

less, demand some of the unrealistic prerequisites: channel state information, bit-level synchronization, poor performance with low SNR and only applicable for narrow-band channel.

- *Broadband channel:* Existing efforts only consider the simple case with narrow-band channel. However, real transmission usually takes place in a broadband channel. Some new challenges should be faced in the real world, e.g. frequency-selective fading. In [18], the analog network coding is extended to the broadband channel with frequency-selective fading.
- *Multiple Antenna:* This is only a straightforward application of traditional physical-layer network coding [17].

II. Challenges in PNC and Potential Topics

I combine these two topics together since they are correlated.

- As stated in our latest paper, current work on physical-layer network coding only focus on the two-way relay channel or the intra-session coding for unicast. We can further extend the physical-layer network coding to multicast applications, with the consideration of intra-session and inter-session coding opportunities.
  - *Challenge:* The challenge is that physical-layer network coding works on the bottom layer, which only cares about the encoding-decoding and modulation-demodulation, while the multicast is on the upper layers, which need topology control, routing and sometimes link scheduling.
  - *Method:* Cross-layer design may be required to implement the multicast objective into the physical-layer. Besides, we may discard the current pattern of physical-layer network coding and invent something new. For example, a novel coding method works in the similar way with linear network coding or erasure coding: each wave may be segmented and further coded; spread out coded waves; recover and demodulate the original wave by collecting enough coded waves.
- Static network topology and narrow-band channel are assumed in current literature since the algorithm design and analysis under this assumption is simpler. However, in wireless networks, node mobility is an important feature that distinguishes itself from wireline network. Besides, real world transmissions are usually in a broadband channel. We may consider mobility in broadband wireless networks with physical-layer network coding.
  - *Challenge:* The model will be much more challenging than that of static network. For example, apartment from the phase-drift caused by the fading channel, we also need to take into account of the mobility pattern of nodes, which brings in the Doppler Effect leading to the frequency-drift. Besides, a known channel state information cannot be assumed here no matter it is slow-fading or fast-fading, since the channel is always changing with the moving of source and destination.
  - *Method:* The idea of differential modulation may be borrowed to solve the lack of channel state information. I am not sure how to deal with frequency-drift by Doppler Effect now. But I think it may be an interesting topic and am willing to learn more about it.

- Current physical-layer network coding all assume high-SNR scenario. This is because, during the performance analysis, we may ignore the noise propagation. However, not all applications are carried out in high-SNR environment. We may explore the application of physical-layer network coding in low SNR cases.
  - *Challenge:* Although it is not proved rigorously, we can find from current literature and our previous analysis that, in low SNR environment, current PNC or ANC has poor BER performance.
  - *Method:* I have not come up with a clear method yet. My feeling is that cooperative diversity may be a choice here.

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