Device-to-Device Communication and Network Coding: Friends or Foes?

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1. Introduction

Device-to-device (D2D) communication in cellular spectrum supported by a cellular network enables direct communication between pieces of user equipment (UE) [1]–[2]. The main reason for incorporating D2D communication in cellular networks is to exploit the proximity of UEs when engaged in local communication sessions such as social networking, media sharing, or proximity-based services [3].

In the presence of such proximate communication opportunities, D2D has been shown to harvest not only the proximity gain in terms of improved link budget, but also the so called reuse and hop gains [2], [5]–[8]. A key technology component of D2D is *mode selection (MS)*, which selects the cellular or direct communication mode for a D2D pair based on factors such as the current resource situation, traffic load, and interference level [8]. Recognizing the potential of D2D, the research community has proposed efficient scheduling, resource allocation, and power control algorithms that help realize the gains of local communications, while at the same time protecting the cellular layer from interference caused by local traffic [9]. These promising results have triggered standards bodies such as the 3rd Generation Partnership Project (3GPP) to study the possibilities of introducing D2D in future releases of Long-Term Evolution (LTE) networks [4].

Along another line of research, it has been observed that physical layer network coding (NWC) improves the spectrum efficiency by facilitating resource reuse by multiple transmissions and taking advantage of advanced signal processing techniques [10]–[11]. Despite the obvious differences between cellular network-integrated D2D and NWC technologies, both aim to improve spectral efficiency and increase network capacity by enabling tighter reuse of resources. As a related study has noted, NWC can be used, under some assumptions, to further enhance the efficiency of D2D communication by combining cellular and direct transmission in integrated D2D and cellular networks [12]. On the other hand, the joint application of D2D and NWC may be costly in terms of UE capabilities, measurement reports, and signaling, while it is not clear whether an integrated D2D-NWC-based solution for dealing with local traffic results in additional gains over a system that uses *either* D2D or NWC alone. We aim to answer the following questions: (1) Does NWC provide gains in integrated D2D-cellular networks? (2) Does D2D provide gains in a cellular network employing NWC?

Therefore, the purpose of the present letter is to discuss some of the advantages and disadvantages of employing D2D and NWC in cellular networks and to explore the potential of integrating these two technology components in such a way that their joint usage benefits both the cellular and the D2D (local) traffic.

2. Employing D2D and NWC to Support Local Traffic

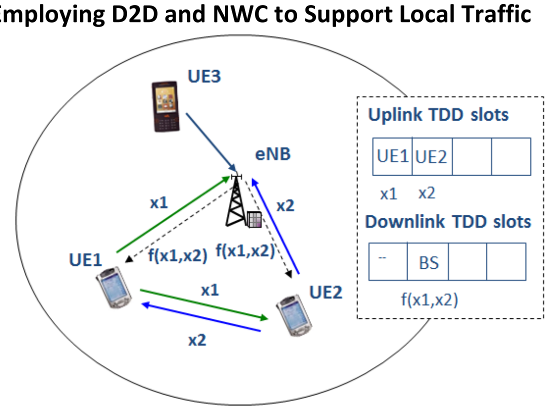

Figure 1: D2D and NWC technologies integrated in a cellular network.

See Figure 1 for a comparison of the operation of D2D and NWC in the presence of local traffic. In this scenario, UE1 and UE2 are served by the same base station (eNB) and engage in a local communication session. D2D technology offers the possibility of direct communication, in which case a bidirectional exchange of signals x_1 and x_2 require two orthogonal resources (because we do not consider the application of full-duplex radio in this letter). For example, assuming time division duplexing (TDD), using D2D, x_1 and x_2 can be sent in subsequent time slots (TS).

If UE1 and UE2 are served by the same eNB in a cellular network employing only physical layer NWC

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(that is, without D2D communication), two time slots can support the exchange of x_1 and x_2. In this case, UE1 and UE2 transmit on the same resource (TS-1), while the eNB uses TS-2 to transmit the NWC data $f(x_1, x_2)$ to UE1 and UE2 simultaneously [10]-[12]. UE1 and UE2 receive $f(x_1, x_2)$ and decode x_2 and x_1, respectively.

As an alternative to the proposed physical layer (also called 2 time slot, 2-TS) network coding scheme, the 3-TS scheme uses different resources for transmitting x_1 and x_2 to the eNB, while the eNB uses TS-3 to transmit $f(x_1, x_2)$. In this 3-TS scheme, the joint application of D2D and NWC becomes possible, as depicted in Figure 1. In the joint mode, UE2 receives *both* the direct transmission from UE1 (in uplink TS-1) *and* the network coded transmission from the eNB (in DL TS-2). UE2 can then employ signal processing (for example, the maximum ratio combined with maximum likelihood detection, as in [12]) to combine the received signals such that the bit error rate is improved over the 2-TS scheme without D2D transmission and reception.

Figure 2 summarizes the possible transmission modes enabled for local traffic by cellular, D2D, and NWC technologies. Note that, in Figure 2, the traditional cellular transmissions (without D2D and NWC) of x_1 and x_2 correspond to a 4-TS scheme [10], since both x_1 and x_2 must be transmitted through the eNB using an uplink *and* a downlink resource.

3. Performance Aspects

In order to gain insights into the advantages of the available local communication schemes, including D2D or NWC alone or in combination, we consider a simplified signal model and use a realistic system simulator to analyze system performance. We evaluate the end-to-end signal-to-interference-and-noise ratio (SINR), total transmit power in the bidirectional transmission ($P_A + P_B + P_R$), and spectral efficiency (a logarithmic function of the SINR divided by the number of required time slots).

Signal Model

The signal models applicable for NWC- and D2D-based transmissions are shown by Figure 3, where *h* denotes the complex channel coefficients and *n* denotes additive Gaussian noise.

Mode Selection

Based on Figure 2 and the signal model, we expect a tradeoff between the number of used resources, invested transmission energy, and the resulting SINR levels, and thereby the achieved spectral and energy efficiencies. Therefore, for an integrated D2D-NWC-cellular network, we developed two MS algorithms that aim to maximize the achieved SINR (MS-NWC 1) and the spectral efficiency (MS-NWC 2), respectively.

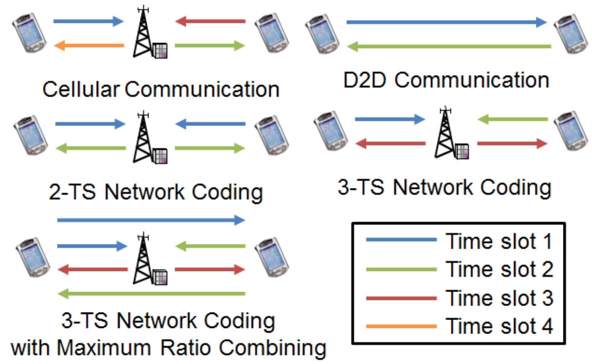

Figure 2: An overview of the available transmission modes for local communications.

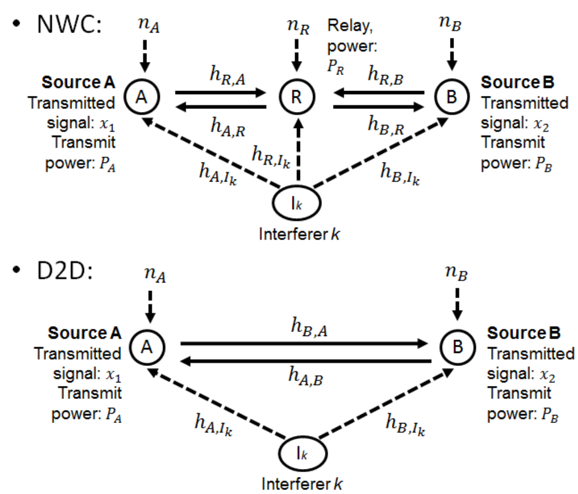

Figure 3: Signal models for NWC and D2D transmissions.

4. Numerical Results

Figure 4 compares the SINR performance of the transmission schemes of Figure 2, along with MS algorithms in a cellular network that supports both NWC and D2D (MS-NWC 1 and MS-NWC 2) and MS in an integrated D2D-cellular network (MS without NWC). The SINR is maximized with proper MS and the gain of employing NWC in an integrated cellular and D2D network in terms of SINR is negligible.

As Figure 5 shows, however, NWC can lead to significant spectral efficiency increase if proper mode selection is employed; for example, MS-NWC 2. This shows that spectral efficiency is the main benefit of introducing NWC into an integrated D2D-cellular network.

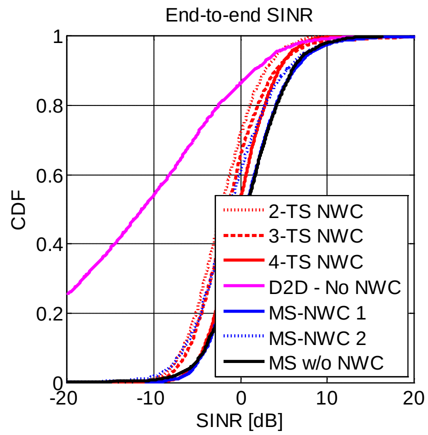

Figure 4: End-to-end SINR performance of the transmission schemes under study.

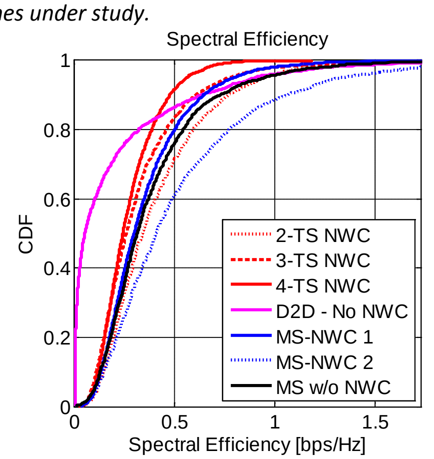

Figure 5: Spectral efficiency of the transmission schemes under study.

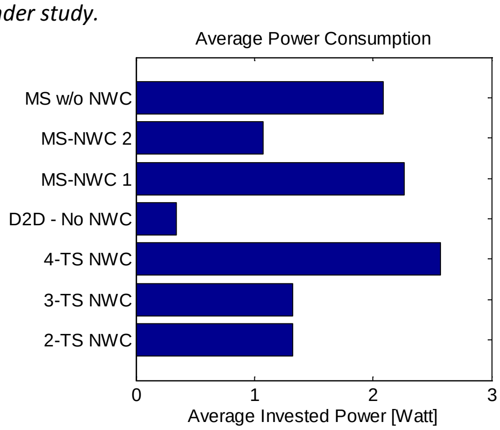

Figure 6: Average power consumption of the transmission schemes under study.

Furthermore, as indicated by Figure 6, this high spectral efficiency can be realized at low power consumption (see Figure 6, MS-NWC 2 column); in other words, a network that supports both D2D and NWC is more energy-efficient than a network that supports only NWC. This is the gain that D2D brings in a cellular network employing NWC.

4. Conclusion

In this electronic letter, we have raised the question of how D2D and NWC technologies can be integrated in cellular networks in scenarios in which local (proximate) communication opportunities exist. Initial investigations suggest that D2D and NWC can complement one another and be friends provided a proper mode selection algorithm is applied by the network.

References

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