Chapter 6.9
Performance Evaluation of a Three Node Client Relay System

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ABSTRACT

In this paper, the authors examine a client relay system comprising three wireless nodes. Closed-form expressions for mean packet delay, as well as for throughput, energy expenditure, and energy efficiency of the source nodes are also obtained. The precision of the established parameters is verified by means of simulation.

INTRODUCTION

Wireless communication networks are becoming more widespread, as novel telecommunication standards emerge (Marks, Nikolich, & Snyder, in press; Nakamura, in press). The future of wireless communication, however, greatly depends on how successfully the disproportion between the required Quality of Service (QoS) and the limited system spectral resource is overcome. Meanwhile, the urge to increase system *spectral efficiency* gradually gives way to the task of the *energy efficiency* improvement. This is particularly true for small-scale handheld wireless devices due to the growing gap between available and required battery capacity (Lahiri, Raghunathan, Dey, & Panigrahi, 2002).

The problem of effective resource utilization is of primary importance for wireless systems, where a large population of users' shares limited spectral resource (Andreev, Koucheryavy, Himayat, Gonchukov, & Turlikov, 2010). Currently, layered system architecture dominates in network design, where each layer is treated independently following the concept of layer abstraction. Among these, *Physical* (PHY) layer is responsible for the transmission of raw data bits, whereas *Media*

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Access Control (MAC) layer arbitrates access of users to the shared wireless channel.

However, traditional layered architecture appears to be far less flexible and often implies inefficient resource utilization (Andreev, Galinina, & Vinel, 2010). To mitigate this discrepancy, a novel integral and adaptive approach is required. As a consequence, cross-layer techniques receive increasing attention from the research community (Andreev, Koucheryavy, Himayat, Gonchukov, & Turlikov, 2010) with primary focus being set on the joint consideration of MAC and PHY layers. New channel-aware solutions are introduced to achieve cross-layer benefits by taking advantage of wireless channel state information (CSI). They typically exploit extended MAC-PHY interaction and result in higher QoS, arrival flow, and channel state adaptability (Song, 2005; Miao, 2008; Kim, 2009).

As wireless users are becoming increasingly mobile, the focus of the latest research efforts shifts from throughput optimization (Song & Li, 2006) towards energy efficiency improvement at all layers of a wireless system (Anisimov, Andreev, Galinina, & Turlikov, 2010) from its architecture (Benini, Bogliolo, & de Micheli, 2000) to the adopted communication protocols (Schurgers, 2002). Recently, *cooperative* cross-layer approaches gain increasing international acclaim (Pyattaev, Andreev, Vinel & Sokolov, 2010; Pyattaev, Andreev, Koucheryavy, & Moltchanov, 2010). They exploit variability in CSI of wireless users and, as such, allow for additional performance gains thus constituting a promising research direction.

RESEARCH BACKGROUND

While more and more users are sharing the limited wireless resource and *cellular* networks are gradually shifting towards more aggressive frequency reuse scenarios (Marks, Nikolich, & Snyder, in press; Nakamura, in press), wireless interference becomes one of the major limiting factors that impair network performance growth. Wireless data transmission of a user, being unavoidably broadcast, necessarily impacts the transmission process of other users and consequently degrades the overall system energy efficiency. However, users may gain in their energy efficiencies by acting cooperatively (Cui, Goldsmith, & Bahai, 2004; Jayaweera, 2004). Such a spatial domain resource management is becoming increasingly important to improve the performance of the cell-edge users with a poor communication link (Andreev, Galinina, & Vinel, 2010).

On the other hand, cooperation typically implies extra energy expenditure as more data is transmitted over the air. Moreover, cooperative transmission may negatively impact packet delay, as data packets are sometimes relayed over a longer path. However, increasing delay could sometimes be compensated by reducing transmission data rate; and this is contrastingly known to increase user energy efficiency (Andreev, Koucheryavy, Himayat, Gonchukov, & Turlikov, 2010). As such, it is important to evaluate all the basic trade-offs behind wireless cooperation and indicate scenarios where it actually improves the performance of a cellular network.

Currently, studying the collaboration between *neighboring* users of a wireless system is highly significant. As energy expenditure to guarantee reliable data transmission exponentially grows with distance (Stuber, 2001), it is desirable to relay data over shorter intermediate hops (Rabaey, Ammer, da Silva Jr., & Patel, 2000). Consequently, *client relay* is believed to become a promising concept that would boost the performance of contemporary wireless cellular networks.

Enabling client relay, it is crucial to avoid scenarios when the use of this technology insufficiently increases the performance of the originating user (Haenggi & Puccinelli, 2005). As the result, the task of effective relay selection is often reduced to analyzing the trade-off between the source node benefits and the relay node losses. In this paper, we evaluate the performance of the

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