Work In Progress: Energy Saving through Cooperation in Wireless Personal Networks

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Abstract— **Recent years have witnessed an explosive growth of wireless technologies and applications. Without disruptive new approaches for energy saving, 4G mobile users will relentlessly be searching for power outlets rather than network access, and become once again bound to a single location. In this paper, we explore the cooperation among nodes in a cluster for the main goal of saving the battery power of mobile terminals. This paper studies the possibility of decreasing energy consumption through relaying data from all nodes in a cluster through the cluster head. A game theoretic framework is considered based on the classical duopoly model of Cournot. This is a trading model in which the relay behaves as the seller and the sources as buyers. Whenever the relay delineates a possibility for revenue, a portion of its resource space is reserved for cooperation for some price, which takes into consideration the degradation in terms of quality of service and the energy consumed from its own battery in forwarding packets on behalf of sources nodes in the cluster. Results demonstrate the gains in energy saving.**

Keywords- WiMedia, WiFi, Energy Saving,Cooperation Schemes, Wireless Personal Netowks, Relaying, Game theory,Cournot duopoly model, Trading models

I. INTRODUCTION

The development and implementation of new kinds of multimedia applications was made possible due to the significant efforts from researches and developers which have striven to develop bandwidth efficient communication systems, without considering the associated costs. As a matter of fact, contrary to the scenario of voice applications, typical of 2G and 2.5G cellular networks, these new multimedia applications are both energy and bandwidth consuming. This has led to highly complex, power hungry devices, requiring advanced signal processing functionalities and putting stringent constraints into battery energy efficiencies.

One of the goals in the design and implementation of 4G wireless networks is the provision of continuous coverage, allowing users to roam freely while having ubiquitous access to network services, which is accomplished by implementing multi-standard radio interfaces (UMTS, LTE, WiFi, Bluetooth) increasing the demand energy at the terminal side. Without disruptive new approaches for energy saving, 4G mobile users will relentlessly be searching for power outlets rather than network access, and become once again bound to a single location [1].

Contrary to the developments in computation and signal processing facilities, it is not expected a similar trend in the evolution path of new kinds of energy efficient batteries which could prolong terminals lifetime. Under such constraints, a possibility for the successful implementation and roll-out of 4G networks and services could be the reduction of the battery energy consumption on mobile terminals [2].

The paper studies the idea of cluster formation, with the cluster head acting as a relay and therefore being responsible for the transmission of data from all mobile nodes in the cluster to the access point (AP). A game theoretic framework is considered based on the classical duopoly model of Cournot. This is a trading model in which the relay behaves as the seller and the sources as buyers. Whenever the relay delineates a possibility for revenue, a portion of its resource space is reserved for cooperation for some price, which takes into consideration the degradation in terms of quality of service and the energy consumed from its own battery in forwarding packets for source nodes in the cluster. The paper is organized as follows. Section 2 presents the proposed scenario for the evaluation of the proposed model. Section 3 introduces the trading model and explains the formulation of the cost and profit functions for the relay and source nodes, as well as the analysis of the parameters which affect the game. Finally, section 6 concludes the paper.

II. SCENARIO

One possibility to increase the remaining battery lifetime is through a higher throughput over the radio link. For a constant transmit power, if adaptive modulation and coding scheme is used throughput can be increased by means of a better channel quality at the receiver. As a matter of fact a better channel quality results from the support of external terminals acting as relays with an effect of reducing the effective transmission range to the AP. By forwarding packets on behalf of source nodes to the AP, these relays agree to cooperate with source nodes by devoting some amount of its own battery energy and radio resources solely for this process of cooperation.

A hierarchical network architecture was devised for terminal cooperation. This is illustrated in figure 1. It consists of a small cluster of mobile terminals (nodes). Each terminal is equipped with two wireless interface cards:

- A WiMedia interface card, supporting UWB technology, is used in the implementation of short range communications among the nodes in the cluster. We denote as short range each radio link among a pair of nodes in the cluster.
- A WiFi interface card for the direct transmission to the AP. We denote as long range each radio link between a source node and the WiFi AP.

Whenever a potential for energy saving is envisioned and the required minimum QoS is guaranteed, the short range link is used instead of the direct one to the AP. In this mode of transmission, data packets arriving from the source nodes in the cluster are sent through the relay, which results in a two-hop transmission.

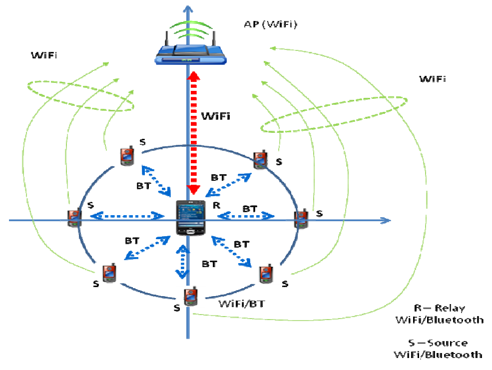

Figure 1. Proposed Scenario for short and long range cooperation

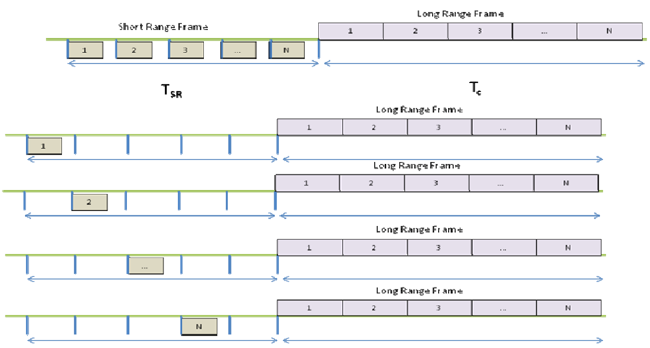

Figure 2. Transmission Protocol

In the scenario proposed for cooperation, transmission is organized into two types of frames in TDMA mode: one for the SRC, with duration T_{sr} seconds, and another one for the LRC with duration T_c seconds. Both frames are organized into N time slots of fixed size (one for each possible collaborating source node in the piconet (which is assumed to be comprised of N source nodes (slaves) and one relay (master). This is illustrated in figure 2. It is assumed that a single packet from each possible source node can be mapped into the respective time slot. The size of the packet will depend on both the data rate achieved at the link from the relay to the AP and to the relay's expected quality of service (QoS). Upon receiving and processing they are conveyed by the relay node to the AP over the long range link to the AP. Provided that adaptive modulation and coding is enabled over the link from the relay to the AP, the transmission bit rate depends on the quality of the channel at the AP's receiver.

III. TRADING MODEL FOR CAPACITY EXCHANGE

As mentioned in previous points the relay's performance is affected by the cooperation mechanism. For one side the amount of energy available in its battery is subtracted from the energy used in the processing and transmission of packets coming from sources. On the other size, relay's quality of service is also affected, as the amount of resources available for its own needs, in terms of packet transmission, is decreased. Therefore, it is normal to expect that the relay will behave selfishly and opt for no cooperation if no incentive mechanism is implemented in the network, which could somehow compensate the relay for the degradation in performance.

Different mechanisms for cooperation incentive were considered in the literature. Roughly these incentives can be classified as mechanisms involving penalties, reimbursement, trading models, tit for tat ... [3]. In this article we consider the classical trading model of Cournot for oligopolistic markets [4]. In the elaboration of our proposed trading model we follow a slightly different approach from the classical model (in the same line as the one in [4]). In our model there is only one seller, the relay, and multiple buyers, the N sources in the cluster. The exchanged resources (goods) are data bits which are mapped into each one of the N time slots of both frames. For a particular scenario, which depends on the quality of the channel at both the AP and the relay receivers, the relay agrees to sell the space pertaining to the transmission of M bits in both TDMA frames. According to this scheme, a maximum of M/N bits may be assigned for each one of the N sources/time slots in the cluster. This is the scenario of a non-cooperative game in which there are two levels of competition:

- As the seller, relay is willing to share a portion of its capacity, consisting of bits over the radio frame to the AP and of its battery's energy in the process of cooperating with source nodes. The relay tries to maximize its which profit. The profit is the difference between the revenue resulting from selling radio resources and the cost resulting from the degradation in quality of service and decrease in available battery energy (decrease in remaining battery lifetime thereof). The price depends on the amount of resources demanded from the buyers (sources) and on the worth of each single bit in the resource space for the relay. The price charged to each user is, therefore, a function of fraction of the capacity and the energy spent in the cooperation process and will assume different values, as the energy cost depends on the quality of the radio channel at the relay's receiver, for the short range communication links.
- As buyers, source nodes compete with other for the resources made available by the relay for bit transmission over both TDMA frames. The amount of bits demanded from the relay depend on the difference between the revenue for each single bit of information borrowed from the relay (in terms of the energy saved if cooperation is enabled in detriment of the direct

transmission to the AP), and the price charged per bit (which depends on the demand from remaining nodes in the cluster)A WiFi interface card for the direct transmission to the AP. We denote as long range each radio link between a source node and the WiFi AP.

For the time being we assume that data bits are exchanged for a virtual price.

A. Game Formulation

We formulate the following trading model:

- **Players:** the nodes in the cluster, including relay and the N source nodes.
- **Actions**: amount of capacity to request from relay: $\mathcal{N} = \{n_1, \ldots, n_i, \ldots, n_N\}$, where n_i is the amount of capacity (number of bits over both radio frames) to request in the forwarding process.
- **Payoffs**: profit for source as well as relay node.

The relay charges a price p per each single bit relayed to the AP on behalf of source nodes. This price encompasses the worth of each single bit of information for the relay and the cost encompasses two different aspects of the cooperation:

i. It reflects the degradation in quality of service for the relay itself due to those resources assigned for the cooperation.
ii. It reflects the energy consumed at the receiver for the processing of those packets sent from source nodes over the short range interface.

The cost assumes different values as the energy per bit depends on the quality of the channel at the AP and the relay, in accordance to the implemented adaptive modulation and coding scheme

B. Cost Function for Relay Node

The cost function reflects the degradation in quality of service for the relay itself due to those resources reserved for cooperation. This price takes into consideration the decrease in QoS for the application being run in the relay. In this work QoS is assumed to be quantified as the required amount of energy for the satisfaction of the QoS (bit rate for example). Our proposed cost function depends on the total amount of bit demanded from source nodes. It is given by equation (1) below.

$$C_r(\mathbf{n}) = \begin{cases} \frac{\alpha}{M}\sum_{i=1}^{N} n_i & \text{if } \sum_{i=1}^{N} n_i \leq M \\ 1 & \text{if } \sum_{i=1}^{N} n_i > M \end{cases} \quad (1)$$

Where:

- $\mathbf{n} = \{n_1, \ldots, n_i, \ldots, n_N\}, i = 1, \ldots, N$ is the vector with the amount of bits assigned per source node.
- $C_r(\mathbf{n})$ is the price charged by the relay and is the same for all sources.
- M is the capacity (in bits over both frames) reserved by the relay for cooperation. It depends on the quality of service expected from relay's own application services.
- α is a scalar which determines the steepness of the cost function $C_r(\mathbf{n})$.
- $\sum_{i=1}^{N} n_i$ is the total amount of capacity demanded from the whole set of source nodes.

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IV. Conclusions

In this research, cooperation is investigated to save battery power in mobile devices. Mobile terminals in the close proximity of each other form cooperative clusters. The head of the cluster acts as a relaying node for the rest of the nodes in the cluster. The cooperation takes advantage of the better channels between the source nodes and the relaying node to achieve higher data rates, resulting in shorter transmission time. Hence, mobile terminals can switch to sleep-mode for longer periods of time, saving more energy. A game theoretic approach is considered in which the relay trades available capacity for a price, which depends of the degradation in quality of service and energy consumed in cooperation. A realistic scenario is considered in the validation of the model: source nodes and relay form a short range cluster into which cooperation is enabled. Future work will establish the trade-off among capacity reservation for the cooperation and the energy consumption which satisfies source sources at the least amount of energy consumption on the relay side.

Acknowledgment

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