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An adaptive packet scheduling algorithm for efficient downlink bandwidth allocation in UWB based wireless infrastructure networks ☆

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Abstract

A short range wireless infrastructure network, in which multiple UWB (ultra-wideband) WPANs are interconnected, is envisioned to be an important platform for various large scale mobile computing applications. It has been suggested that traditional packet scheduling algorithms used in cellular networks can be used for UWB based short-range networks. Unfortunately, these existing algorithms, e.g., HSDPA, cannot properly balance the conflicting goals of maximizing bandwidth efficiency while providing adequate fairness to users. Recently, an efficient scheme called MTA-ISIR is suggested and is found to be effective under several practical scenarios. Nevertheless, we find that there are still some drawbacks in the MTA-ISIR algorithm.

In this paper, we propose two new approaches in which the power level threshold used for handling the fairness is dynamically adjusted for different traffic models. Our first approach is based on the "opportunistic scheduling" concept which enables the scheduler to optimize the bandwidth efficiency without sacrificing fairness. The second approach makes use of the consecutive packet lengths to prioritize users when assigning time slots. Simulation results indicate that the proposed methods outperform MTA-ISIR under a wide range of parameters.

Keywords: UWB (ultra-wideband) systems; Wireless infrastructure networks; Short-range communications; Fast packet scheduling; Environment adaptation; Fairness; Packet queuing delay; Bandwidth efficiency

1. Introduction

Ultra-wideband (UWB) systems are now important platforms for high data rate wireless communications. Characterized by the giga-hertz bandwidth, a typical UWB signal duration is limited in nanoseconds range while the spread energy is very tiny (about a few μW per MHz) [1,19,20]. Indeed, as governed by the Win–Scholtz physical model [1], UWB systems' data rate is a linear function to the signal to interference and noise ratio (SINR) at the receiver end. Thus, by keeping the data rate at a moderate level, a wireless infrastructure network (see Fig. 1), in which multiple UWB "cells" (i.e., WPANs) are interconnected, is highly feasible. Specifically, in such an infrastructure network, nodes can be divided into various sectors in the network, and in each sector, nodes share one high rate UWB data channel in a TDMA manner.

Previous results in [19,20] reveal that all nodes within a single UWB network should transmit data with extreme power levels (maximum or zero) to achieve the best tradeoff between throughput and fairness. However, in a power-constrained UWB infrastructure system as depicted in Fig. 1, to avoid inter-sector interference, it may be infeasible

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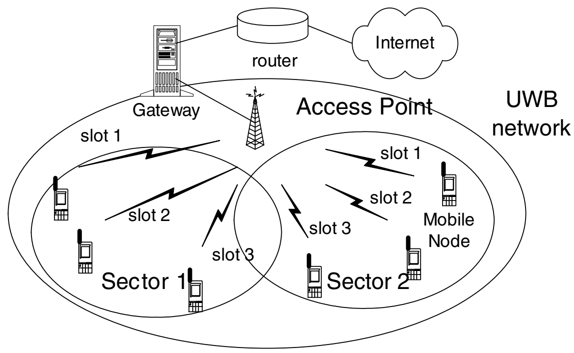

Fig. 1. An example of a UWB based large scale infrastructure network.

for the access point nodes in different sectors to transmit with peak powers simultaneously. Since UWB system's rate is proportional to the SINR at the receiver, an efficient scheduling scheme has to be able to allocate higher rates to users with higher values of SINR in order to increase the utilization of the precious wireless bandwidth.

Due to the similarity of structure between the above mentioned UWB based infrastructure networks and traditional cellular networks, it has been suggested cellular packet scheduling algorithms [2–4, 8–10] can be used for the former as well. Indeed, traditional algorithms such as the *high-speed downlink packet access* (HSDPA) system are considered by many researchers. Furthermore, proportional fairness (PF) based approaches are also applied in UWB systems [21]. For example, a PF based scheduler characterized by *queue-based exponential* (QBE) rule is suggested in [18] to improve system throughput. Specifically, taking node k's queue length q_k and queue delay d_k into consideration, the scheduler selects a user which maximizes:

$$a_k \frac{Q_k}{\overline{Q_k}} \exp\left(\frac{a_k d_k - \overline{ad}}{1 + \sqrt{\overline{ad}}}\right) \cdot \exp\left(\frac{q_k - \overline{q}}{1 + \overline{q}}\right), \quad (1)$$

where Q_k is node k's CIR, a_k is the assigned weight to indicate the desired service level, and $\bar{x}$ denotes the average of x during the scheduling epoch.

Unfortunately, these existing practical techniques fail to properly balance the conflicting goals of maximizing bandwidth efficiency and providing adequate fairness in a wideband system such as a UWB based infrastructure network considered in this paper.

Recently, Ofuji et al. [6] have done some pioneering work in addressing the practical issues involved in the design of an efficient scheduler that can handle the above mentioned challenges well. Specifically, they propose a new scheduling technique called *minimum throughput assured instantaneous interference power ratio* (MTA-ISIR). The MTA-ISIR scheme is designed to strike a balance between system throughput and fairness. To achieve this, MTA-ISIR only "updates" users with power levels lower than a threshold Q_w and then compares them to the current user for slots assignment. For those users with average power levels higher than Q_w, they content for time slots based on the CIR consideration as usual. The instantaneous received SIR in the kth time slot for user i after the "updating" process is given by:

$$Q_k^{i\prime} = \begin{cases} Q_k^i, & Q_{\text{avg}}^i \geqslant Q_w \\ Q_k^i \times \frac{Q_w}{Q_{\text{avg}}^i}, & \text{otherwise} \end{cases} \quad (2)$$

where Q_w is a fixed power level determined by simulations. The user with the maximum updated instant power level $Q{\prime}_k^i$ is allocated the slot. A relatively salient value of Q_w is determined in [6] under the simulation environment considered in their study. Indeed, the MTA-ISIR scheme is found to be quite efficient [6] under various practical scenarios.

To illustrate, let us consider a simple example as shown in Fig. 2. Here, as user 2 bears a worse channel than user 1 does, M-CIR assigns all the slots to user 1 while the PF constraint induces a fair distribution. MTA-ISIR and QBE both try to balance the allocations between M-CIR and PF. Furthermore, MTA-ISIR has a higher system throughput since user 1 is assigned one more slot than that by QBE. Here Q_w is the reference power level used in Eq. (2), $Q_{\text{avg}i}$ is the average power level of user i, $Q'_{\text{avg}i}$ is the updated power level according to Eq. (2) of user i.

However, as evident in the example above, a major drawback of the MTA-ISIR scheme is that the key parameter, Q_w, has to be determined by prior simulations and is a fixed value in the algorithm. Obviously, in a real operating environment, it may be infeasible to obtain an accurate value of Q_w *a priori*. Thus, in this paper, we propose an *environment adaptive* MTA-ISIR (EA-MTA-ISIR) scheduling strategy by dynamically changing Q_w in various environments. Indeed, in our preliminary study of the MTA-ISIR scheme, we find that within a group of users (i.e., for those users with power levels lower than the threshold), the rates assigned could differ from each other

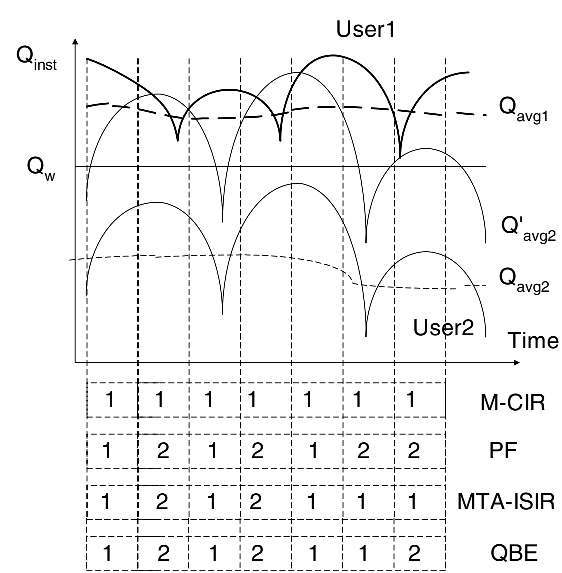

Fig. 2. An illustrative example of existing scheduling schemes.