On End-to-End Scheduling in Wireless Cellular Networks

Walid Saad, Zaher Dawy, and Sanaa Sharafeddine

Abstract—Wireless cellular networks are required to meet the stringent QoS requirements of emerging data services. To efficiently utilize the available radio resources, we propose a new resource allocation algorithm for services that require end-to-end guarantees. Unlike existing literature that mainly focuses on uplink only or downlink only scheduling algorithms, the proposed algorithm aims at ensuring an end-to-end utility value reflecting end-to-end QoS in terms of delay and channel quality. By jointly considering the time varying channel conditions in both uplink and downlink directions, the proposed end-to-end scheduling algorithm achieves an increased number of active connections, a lower packet drop, and an increased net throughput in comparison to other schemes. These gains are achieved with a tradeoff cost in terms of complexity and signaling overhead. For overhead reduction in a practical setting, we propose an implementation over clusters within the network.

I. INTRODUCTION

Data services such as video streaming and interactive gaming are highly resource demanding, thus imposing stringent QoS requirements on wireless cellular networks. Many of these services involve end-to-end communication between an uplink mobile station (MS) transmitting packets to a downlink MS. Such services require end-to-end QoS guarantees in terms of channel quality and delay. Existing publications on resource allocation for cellular networks focus on single-link scheduling: scheduling in uplink only or scheduling in downlink only. Furthermore, although some work also considers cooperation among multiple base stations (BSs) in cellular networks, the cooperation is limited to single-link operation. In this work, we propose a new end-to-end scheduling algorithm that jointly considers the uplink and downlink channel conditions of the different communication links in the network. This novel scheduling algorithm is distinguished by its opportunistic nature as it permits collaboration between uplink and downlink for achieving the target end-to-end QoS. It achieves significant gains in terms of lower packet drop and increased net throughput. For practical implementation, a cluster-based approach can be used in order to limit the signaling overhead among uplink and downlink BSs.

The paper is organized as follows. Literature survey is done in Section II. Section III introduces the concept of end-to-end scheduling. Section IV describes the system model and Section V presents the proposed scheduling algorithm. Simulation results are presented and analyzed in Section VI. In addition, Section VI tackles implementation concerns for end-to-end scheduling. Finally, conclusions are drawn in Section VII.

II. LITERATURE SURVEY

In [1], an uplink scheduling algorithm for data services in a single cell CDMA network is proposed. A game theoretical approach is used and the uplink power control problem is modeled as a non cooperative game possessing a Nash equilibrium point. A utility function characterizing each mobile’s QoS in terms of frame success rate (FSR) and throughput is used. The authors in [2] extend the work of [1] to a multi-cell network and present a joint base station (BS) assignment along with the power allocation algorithm aiming at maximizing individual MS utility. The paper utilizes pricing in terms of transmit power in order to achieve Pareto efficiency. The authors in [3] derive a heuristic packet based uplink scheduling algorithm in a CDMA network. The algorithm prioritizes the different packets and schedules them accordingly while providing throughput and frame error rate guarantees.

In [4], a joint BS assignment and scheduling algorithm for the downlink is considered. The purpose is to maximize the total utility per individual BS through scheduling in two phases: a mobile selection phase and a power allocation phase. In [5] and [6], the downlink resource allocation problem for a multi-cell heterogenous CDMA system is studied. Both papers take into account the non-critical delay requirements of the services and solve the problem heuristically using the multiple choice multi-dimensional knapsack (MMKP) algorithm. The suggested solution aims at maximizing the total system utility. The authors in [7] present a novel downlink scheduling algorithm based on [5] and [6]. The derived algorithm allocates the total available transmit power of the BS to one MS only during the transmission of a frame within a time slot. Unlike previous work, the utility function is defined per packet and not per user. The MMKP-based solution gives in a combined matrix the BS assignment as well as the scheduled packets. The results in terms of utilities are compared with two other systems defined in the paper. Another contribution for the downlink resource allocation problem is provided in [8] for scheduling at the level of a cluster of interdependent BSs. The aim of the paper is to find a power allocation algorithm that maximizes throughput and fairness in a CDMA system.

III. END-TO-END SCHEDULING: MOTIVATION

The review in Section II focused on efficient single-link scheduling algorithms suitable for uplink only or downlink only scenarios. Cooperation among BSs and exchange of information between various BSs in a cellular network have been as well proposed in the literature, but also for single link scenarios. E.g., the authors in [9] present a downlink scheduling algorithm that requires a centralized node which schedules, in addition to the MSs that will be served in a time slot, the BSs that will be active during that slot within...
a selected cluster of cells. The centralized node is required to gather channel information from all the BSs in a cluster of cells prior to making scheduling decisions. Another recent contribution for downlink fair scheduling that also requires a centralized scheduler to control a group of cells is presented in [10]. Coordination among BSs for various uplink or downlink related problems is also tackled in [11], [12], and [13].

Nevertheless, many of the person-to-person services such as video telephony and mobile gaming require end-to-end QoS guarantees between two communicating MSs: an uplink user which is sending packets to a downlink user. In such scenarios, the single-link algorithms, even with BS coordination, tend to be inefficient for various reasons. On one hand, ensuring end-to-end QoS such as end-to-end delay for the previously mentioned services is difficult to achieve when having independent uplink and downlink single-link schedulers in an end-to-end connection. On the other hand, single-link schedulers applied to end-to-end scenarios yield wasted resources, for example by allocating power to an uplink user whose downlink recipient is currently experiencing a bad channel. These shortcomings coupled with the emergence of many end-to-end data services motivated the development of an end-to-end scheduling algorithm that jointly accounts for the channel quality of both the uplink and downlink users prior to selecting a frame to be transmitted. The proposed scheduler would be able to enable some sort of collaboration between the uplink and downlink channels. Finally, unlike previous work, which fulfilled only single-link QoS and/or utility requirements of the services, the proposed scheduler permits an end-to-end utility value guarantee capturing the QoS requirements of the service. These benefits are achieved at a tradeoff cost in terms of complexity and signalling overhead as discussed in Section VI-C.

IV. SYSTEM MODEL

A. Network Model and Channel Quality

We consider a time-slotted multi-cell CDMA cellular system having $C$ BSs with $2K$ MSs belonging to a single data service. The set of all BSs in the network is denoted by $\mathcal{C} = \{1, 2, \ldots, C\}$. Additionally, the MSs will be considered in communicating end-to-end pairs referred to as “connections”.

Thus, each connection denotes two MSs involved in an end-to-end session whereby an uplink MS is sending packets to another MS receiving these packets in the downlink. The two MSs involved in a connection can be located in different cells or in the same cell. Within a time slot of duration $\theta$, we assume that an uplink user transmits only one packet of length $L$ to its corresponding downlink recipient. The considered path loss model accounts for both distance based path loss and correlated shadowing with $g_{i,c_i}$ as path loss attenuation between a MS $i$ and its serving BS $c_i \in \mathcal{C}$. The BS assignment scheme is path loss based.

The FSR is used as in [2], [4], [5] and [6] to indicate uplink and downlink channel quality. The FSR is directly related to the bit error rate (BER) $P_e$, which in turn is a function of the SIR depending on the modulation scheme. As in [2], the FSR expression for a packet of length $L$ bits is given by

$$f = (1 - P_e)^L$$

For a connection between an uplink MS $i$ and a downlink MS $j$, the SIR of MS $i$ received by its BS $c_i \in \mathcal{C}$ is given by

$$\Gamma_{i,c_i} = \frac{g_{i,c_i} P_{i,c_i}}{\sum_{k=1}^{K_c} g_{k,c_i} P_{k,c_i} + \alpha P_R + \sigma^2}$$

where $S_{i,c_i} = W/R_{i,c_i}$ represents the uplink spreading factor, $W$ is the chip rate, $R_{i,c_i}$ is the data rate of MS $i$, $P_{i,c_i}$ is the transmit power of MS $i$, $P_R = \sum_{k=1}^{K_c} g_{k,c_i} P_{k,c_i}$ is the total received power at BS $c_i$, $K_c$ is the number of active users served by BS $c_i$, $\alpha$ is the intercell to intracell interference factor, and $\sigma^2$ is the variance of the additive Gaussian noise.

Furthermore, the SIR of downlink MS $j$ as received from its serving BS $c_j \in \mathcal{C}$ is given by

$$\gamma_{j,c_j} = \frac{S_{j,c_j}}{\lambda g_{j,c_j}(P_{j,c_j} - \beta_{j,c_j}) + \alpha \beta_{j,c_j} P_{c_j} + \sigma^2}$$

where $S_{j,c_j} = W/R_{j,c_j}$ represents the downlink spreading factor, $R_{j,c_j}$ is the data rate of MS $j$, $P_{j,c_j}$ is the transmit power allocated to MS $j$ by BS $c_j$, $P_{c_j}$ is the total transmit power of BS $c_j$, $\lambda$ is the orthogonality factor, and $\alpha$ is the intercell to intracell interference factor of MS $j$.

B. End-to-End Delay

In this work, we consider that the main end-to-end delay component is the queuing delay or waiting time. We assume that for end-to-end packet delivery in a time slot, a packet is either transmitted from end to end or it waits at the level of the uplink BS if the destined downlink MS is experiencing a bad channel. Therefore, no additional queuing delay is incurred at the downlink BS level and, thus, the queuing delay component resides only at the level of the uplink MS.

A service specific maximum tolerable end-to-end delay $\tau$ is defined for every packet. We consider that after $\tau$ has elapsed the packet will be dropped and the user will receive a new packet from upper layers. Moreover, we define $d$ as the remaining tolerable delay in a time slot for a particular transmission direction, $d$ is thus formulated as

$$d = \tau - q\theta$$

where $\theta$ is the duration of a time slot and $q$ is the number of time slots elapsed since the packet was generated.

C. Utility and Debt

A utility function per direction (uplink or downlink) will be defined as an increasing function of the FSR in the considered direction and a decreasing function of the remaining tolerable delay $d$ (i.e. waiting time). By having joint end-to-end scheduling within a time slot, the value of $d$ in the utility of the downlink will always be 0 since no waiting time occurs at the level of the downlink BS as explained in subsection IV-B; whereas the value of $d$ for the uplink reflects the queuing time. In consequence, the total “profit” experienced by the network
for granting an end-to-end packet transmission opportunity for a connection $l$ between MS $i$ and MS $j$ will be captured by an end-to-end utility defined as

$$u_l = v_i + w_j$$  \hspace{1cm} (5)

where $v_i$ and $w_j$ are the utilities of the uplink and downlink transmissions, respectively. The summation of an uplink and a downlink utility for quantifying the end-to-end utility is analogous to summing the utilities of all MSs in a network to compute the total system utility as done in [5], [6], and [7].

Furthermore, the main goal of the proposed scheduler is to ensure end-to-end QoS. For this purpose, the scheduler will guarantee an end-to-end target utility value $\tilde{u}_l$ for every connection in the network. This target utility is implied by the required target FSR and target end-to-end delay. To guarantee both delay and channel quality, the scheduler will permit a trade-off of channel quality for the sake of transmitting in time while maintaining the target end-to-end utility value. For a connection $l$, this end-to-end utility guarantee maps into

$$u_l \geq \tilde{u}_l$$  \hspace{1cm} (6)

Equations (5) and (6) yield the following

$$\begin{cases} v_i \geq \tilde{v}_i & \text{for the uplink} \\ w_j \geq \tilde{w}_j & \text{for the downlink} \end{cases}$$  \hspace{1cm} (7)

where $\tilde{v}_i$ and $\tilde{w}_j$ are the target utilities for the uplink and downlink, respectively. These target utilities are computed based on the uplink and downlink collaboration which is explained in following sections. A minimum allowable FSR $\beta$ is defined as follows for every transmission direction: $f = f - \epsilon$, where $f$ is the target FSR and $\epsilon$ is a margin FSR value which is set depending on the required minimum FSR. This minimum FSR enables the scheduler to provide a minimum FSR limit for the FSR-delay trade-off. Hence, the maximum FSR margin that the scheduler is allowed to trade off for the purpose of allowing a transmission in time is $\epsilon$. Consequently, the minimum allowable FSR provides a minimum channel quality bound to be respected by the scheduling algorithm. Substituting the values of the minimum FSR in the end-to-end utility function for each connection, leads to a minimum end-to-end utility value $\tilde{u}_l$ per time slot.

Finally, the debt $\delta_l$ of a connection $l$ is defined as the amount of end-to-end utility required by this connection in order to achieve its target utility value; consequently guaranteeing the required end-to-end QoS in terms of delay and FSR. Hence, the debt is given by

$$\delta_l = \tilde{u}_l - \tilde{u}_l$$  \hspace{1cm} (8)

The value of $\delta_l$ allows the scheduler to assess the required resources that should be allocated in the uplink and the downlink for connection $l$ in order to ensure end-to-end QoS.

D. Priority

Each connection $l$ in the network will be assigned a priority based on the experienced channel and delay within a time slot. The priority function $\phi_l$ of a connection $l$ is an increasing function of channel quality and a decreasing function of $d$.

V. END-TO-END SCHEDULING ALGORITHM

In every time slot, the stages of the proposed end-to-end scheduling algorithm are specified by Algorithm 1.

**Algorithm 1 Proposed end-to-end scheduling algorithm.**

for $l = 1$ to $K$ {Loop through all connections, each connection $l$ has an uplink user $i$ sending packets to downlink user $j$.}

**Stage 1. Prioritization stage.**

Compute priority and debt for all connections.

end for

Connections Sorting. Sort connections by decreasing priority order

for $l = 1$ to $K$ {Loop through connections which were sorted by priority}

**Stage 2. Debt sign inspection.**

if $\delta_l > 0$ then

Debt is positive, share the debt fairly between uplink and downlink in order to achieve fair contributions to the end-to-end utility debt between the two transmission directions.

else

Debt is negative or zero, scheduler connection with minimum allowable FSR.

end if

**Stage 3. Power allocation.**

Compute uplink and downlink powers $P_{u,c_i}$ and $P_{d,c_j}$ for connection $l$. The power values are acceptable, if they satisfy the maximum power constraints for uplink and downlink in equation (14).

end for

A. Prioritization Stage

In the first stage, the scheduler proceeds connection by connection and computes the values of the priority and debt. The output of this first stage is a prioritized listing of all packets with their respective debt value. Following this first stage, the scheduler proceeds connection by connection, by priority, while performing sequentially the other two stages.

B. Debt Sharing Stage

In this stage, the scheduler inspects the sign of the debt $\delta_l$ for each connection $l$ between uplink MS $i$ and downlink MS $j$. For instance, if $\delta_l > 0$ the scheduler must fairly share this positive debt between the uplink and the downlink MSs of the connection by taking into account the channel conditions of each direction. This uplink/downlink debt sharing problem can be mapped to the problem of a rich and a poor man who have a debt of $\delta_l$ dollars to a bank. For example, a 100$ debt split equally between the two men is not a fair distribution. For the sake of assessing fairly the contribution of each man, a “contribution” utility will be defined for every man and would be a function of the debt share as well as the man’s wealth. In our scheduling problem, the rich man maps into the MS with better channel conditions (reflecting the wealth) and the poor man maps into the MS with worse channel conditions. The contribution utilities reflect the “real” contribution in terms of utility for every direction; thus allowing the scheduler to enable some sort of uplink/downlink collaboration for ensuring end-to-end utility.

We define $\rho$ and $\beta = 1 - \rho$ as the fractions of the whole debt $\delta_l$ paid by the uplink and downlink respectively. Additionally, we define two “contribution” utilities $h_i(\rho)$ for the uplink and $o_j(\beta)$ for the downlink. These utilities will be a decreasing
function of channel quality and an increasing function of the debt share. This relationship is chosen such that the channel with better conditions would require a share of the debt higher than the other direction, in order to achieve a particular contribution value. For allowing a fair debt share between the uplink and downlink users, we assume that each direction must contribute equally to the debt such that

$$h_i(\rho) = o_j(\beta)$$  \hspace{1cm} (9)$$

Solving (9) yields the share of the debts for each direction. Subsequently, powers are allocated to connection \( l \) by solving the following equations deduced out of (7) and (8)

$$\begin{cases} v_i \geq \bar{v}_i + \rho \cdot \delta_l & \text{for the uplink} \\ w_j \geq \bar{w}_j + \beta \cdot \delta_l & \text{for the downlink} \end{cases}$$

(10)

where \( \bar{v}_i \) and \( \bar{w}_j \) are the minimum allowable utilities for the uplink and downlink, respectively. Finally, through (8), it can be noted that if \( \delta_l \leq 0 \) then the connection in this time slot is able to achieve its utility target with minimum allowable uplink and downlink utilities. In this case no debt sharing is needed and the scheduler will schedule connection \( l \) with minimum utility requirements by setting \( \rho = 0 \) and \( \beta = 0 \) in (10).

C. Power Allocation Stage

In this stage, the scheduler computes the powers for the uplink and the downlink of a connection \( l \). In fact, after performing some computations, (10) yields the following:

$$\begin{cases} \Gamma_{i,c_i} \geq \bar{\Gamma}_{i,c_i} & \text{for the uplink} \\ \gamma_{j,c_j} \geq \bar{\gamma}_{j,c_j} & \text{for the downlink} \end{cases}$$

(11)

where \( \bar{\Gamma}_{i,c_i} \) and \( \bar{\gamma}_{j,c_j} \) are the target SIR values for the uplink MS and downlink MS, respectively. Substituting \( \Gamma_{i,c_i} \) and \( \gamma_{j,c_j} \) with their expressions given in (2) and (3), (11) yields the power expressions given in (12) and (13) for the uplink and downlink users \( i \) and \( j \) of connection \( l \), respectively.

$$g_{i,c_i}P_{i,c_i} \geq \frac{\bar{\Gamma}_{i,c_i}}{\bar{S}_{i,c_i}}(P_R(\alpha + 1) + \sigma^2) (1 + \bar{\Gamma}_{i,c_i}^\alpha)$$

(12)

where \( P_R = \sum_{k=1}^{K_c} g_{k,c_k}P_{k,c_k} \) represents the total received power at the uplink BS \( c_i \) and \( K_c \) represents the number of users assigned to BS \( c_i \) that have been scheduled prior to and including the user \( i \) of the considered connection \( l \).

$$P_{j,c_j} \geq \frac{\bar{\gamma}_{j,c_j}}{\bar{S}_{j,c_j}}(g_{j,c_j}P_{j,c_j}(\lambda + \alpha_j) + \sigma^2) g_{j,c_j}(1 + \bar{\gamma}_{j,c_j}^\alpha)$$

(13)

where \( P_{j,c_j} \) represents the total transmit power of BS \( c_j \) for the connections that have been scheduled prior to and including user \( j \) of connection \( l \). The maximum uplink MS transmit power \( P_{MS} \) and the maximum downlink BS transmit power \( P_{BS} \) are accounted for as follows:

$$0 < P_{i,c_i} \leq P_{MS}, \hspace{1cm} 0 < P_{j,c_j} \leq P_{BS}$$

(14)

Furthermore, the computation of the uplink total received power \( P_R \) and the downlink total transmitted power \( P_{c_j} \) is inspired from [14], whereby the scheduler sums all inequations of the form (12) and (13) for all connections that were processed in priority order up to and including the considered connection \( l \). Acceptable values of \( P_R \) and \( P_{c_j} \) are substituted for all the already scheduled connections for testing whether scheduling \( l \) yields a disconnection for any previously scheduled connection due to violation of constraints (14). In case no other connection is affected, \( l \) would be granted transmission. At the end of power allocation for all network connections, the scheduler would have selected the different end-to-end sessions that should transmit within a time slot.

VI. RESULTS AND IMPLEMENTATION CONCERNS

A. Proposed Expressions

The proposed algorithm is generic in the sense that any expression for priority, utility, and contribution utility can be used as long as it satisfies the relationships explained in the previous sections. In (15) and (17), we propose expressions for the priority and the contribution utility that fulfill the design objectives previously mentioned. In (16), we propose a utility function inspired from [5]. The selected expressions for priority, utility, and contribution utility were further tweaked based on extensive simulation scenarios.

$$\phi_l = \frac{\bar{g}_{i,c_i}}{\bar{S}_{i,c_i}} \frac{\bar{g}_{j,c_j}}{\bar{S}_{j,c_j}}$$

(15)

$$\begin{cases} v_i(\Gamma_i,d_i) = (1 - Q(\sqrt{2\bar{\gamma}_{i,c_i}}))^L \cdot e^{\frac{-\bar{\gamma}_{i,c_i}}{2\bar{S}_{i,c_i}}} \\ w_j(\gamma_j,d_j) = (1 - Q(\sqrt{2\bar{\gamma}_{j,c_j}}))^L \cdot e^{\frac{-\bar{\gamma}_{j,c_j}}{2\bar{S}_{j,c_j}}} \end{cases}$$

(16)

$$h_i(\rho) = \frac{\rho}{\bar{g}_{i,c_i}^\alpha}$$

(17)

for the uplink MS \( i \) and

$$o_j(\beta) = \frac{\beta}{\bar{g}_{j,c_j}^\alpha}$$

for the downlink MS \( j \)

where \( \bar{g}_{i,c_i} \) and \( \bar{g}_{j,c_j} \) represent the average pathloss for the uplink and the downlink, respectively. Note that, without loss of generality, BPSK modulation is assumed for the FSR expressions. Any other modulation technique will still be valid and can be used with the proposed algorithm.

B. Results and Analysis

The set of parameters describing the simulated cellular network are summarized in Table I. Figure 1 shows the average number of active connections (selected to transmit) in a time slot as the number of users per BS increases for different end-to-end delay targets. This figure shows that higher network loads yield an increase in the average number of active connections; emphasizing the multiuser diversity capabilities of the proposed end-to-end scheduler. Moreover, Figure 1 demonstrates the opportunistic nature of the proposed scheduler by highlighting the fact that as the target delay is lower the active connections in a time slot increase, in order to maintain the end-to-end delay requirements and allow packets to be transmitted before reaching their deadline.
In order to assess the performance of the proposed scheduler, we define in this work two other end-to-end schedulers. The first is composed of single-link independent uplink and downlink schedulers applied to the end-to-end scenario (referred to as “independent scheme”), based on simplified versions of the algorithms in [3] and [14] for the uplink and downlink, respectively. Comparing with the independent scheme will emphasize the waste of resources incurred by having single-link schedulers in end-to-end scenarios. The second is similar to the proposed scheme but with no FSR-delay trade-off and no uplink/downlink cooperation (referred to as “basic scheme”). Hence, comparing with the basic scheme will emphasize collaboration and trade-off gains. Note that we will refer to our proposed algorithm as “joint scheme”.

In Figure 2, a comparison of the achieved average number of active connections is presented. The proposed joint scheme achieves significant active connections gains over the basic and independent schemes for all network loads. Furthermore, we notice that the basic scheme which emphasizes priority-only gains has small improvements over the independent scheme. This demonstrates that the gains of the proposed joint scheme are mainly due to collaboration between uplink and downlink.

In Figure 3, we compared the net throughput of the joint scheme...
with that of the basic and independent schemes. Results show that with 60 users per cell, the joint scheme achieves gains in net throughput of 30% over the independent scheme and 25% over the basic scheme.

C. Practical Implementation Considerations

For the purpose of end-to-end scheduling, knowledge of uplink and downlink channel information for each end-to-end connection is needed. In consequence, some exchange of information between uplink and downlink BSs is required. Exhaustive literature has already explored the possibility of exchange of information among BSs in cellular networks for the purpose of downlink scheduling, uplink scheduling, or performance enhancement such as in [9], [10], [11], [12], [13].

In order to implement the proposed end-to-end scheduling approach in practice, a clustering approach can be used in order to reduce the signalling overhead and allow the end-to-end scheduling decision to be made in a timely manner. Such a clustering approach is already used for implementing the centralized downlink scheduler in [9]. The main idea proposed in [9] is to divide the network into small clusters and implement BS coordination and centralized scheduling at the level of each cluster. For end-to-end scheduling, we can assume that the network is divided into clusters of cells whose BSs are served by a centralized node and consider end-to-end scheduling within each cluster only (see example scenario in Figure 4). In fact, such an implementation yields a tradeoff between the cluster size and the end-to-end scheduling gains. The bigger the size of the cluster, more end-to-end connections will be available and, thus, more performance gains will be achieved. However, more information collection, processing, and signalling overhead will be required. On the other hand, a small cluster size will still allow for notable gains for end-to-end scheduling with low complexity and signalling overhead. For example, the simplest scenario, which results in the smallest cluster size, is to implement the proposed approach within the coverage area of one BS site. Even in this case, gains are achieved especially in rural areas with large coverage and where local mobile subscribers communicate with each other over the cellular network.

In order to extend end-to-end scheduling to multiple clusters in the network, communication between the centralized nodes of the clusters would be required, e.g., via high bit rate links in the transport domain of the core network [15].

VII. CONCLUSIONS

In this work, we propose a novel approach for resource allocation in wireless cellular networks suitable for end-to-end services. The algorithm schedules the users in communicating pairs while ensuring an end-to-end utility value reflecting end-to-end QoS parameters such as end-to-end delay and channel quality. The proposed algorithm yields significant improvements over traditional schemes in terms of higher average number of active connections, lower packet drop, as well as an increased net throughput.

Fig. 4. Centralized node hosting end-to-end scheduler in a cluster of 7 cells.

REFERENCES