QoS Provisioning in the Absence of ARQ in Cellular Fixed Relay Networks through Inter-Cell Coordination[1]

Mahmudur Rahman and Halim Yanikomeroglu
Broadband Communications and Wireless Systems (BCWS) Centre
Department of Systems and Computer Engineering
Carleton University, Ottawa, Canada K1S 5B6
E-mail: {mmrahman,halim}@sce.carleton.ca

***Abstract*—We propose an interference management scheme for providing *quality of service* (QoS) in the absence of *automatic repeat request* (ARQ) in cellular networks augmented with fixed relays. The high packet error rate in a system with ARQ not only incurs additional packet delay, which is undesirable for real-time services, but also reduces link throughput because of the increased over-the-air signaling overhead and retransmissions. The proposed scheme strives for improvements in packet error rate and net throughput while maintaining acceptable delay through the use of inter-cell coordination. The inter-cell coordination uses backbone network for information exchange and thereby transfers over-the-air signaling overhead to the high-speed backbone network. In our scheme, a group of base stations, each of which is either a recipient of or a contributor to dominant interference, form an *interferer group* and exchange channel state information with each other. Based on this instantaneous channel quality information, the proposed scheme makes intelligent scheduling and routing decisions taking the interference into account. The performance of the scheme is compared with that of an uncoordinated scheme through extensive simulations. It has been observed that the proposed scheme achieves significant performance benefits in terms of packet error rate and net throughput.**

***Index Terms*—Base Station Coordination, Radio Resource Management, Interference Management, Cellular Relay Networks, Multihop Networks, Dynamic Interference Aware Scheduling, QoS in non-ARQ systems.**

I. INTRODUCTION

The extraordinary growth of Internet and the evolution of ranges of modern wireless devices demand increasingly high data rate wireless applications for various services from voice to streaming video. One of the goals of the Wireless *World INitiative NEw Radio* (WINNER) [1] is to provide high wireless data rates ubiquitously in an *always-the-best* manner. In order to support such rates with scarce spectrum, any wireless system has to reuse resources in time and/or frequency and/or space domains. An obvious pitfall of resource reuse is the co-channel interference, and consequently, increased packet error rate. The ARQ has been known to be ineffective for delay-sensitive services due to its latency. Furthermore, for a network with relays [2] as envisioned in the WINNER, required end-to-end ARQ over multiple segments of the route pose additional challenges in meeting QoS requirements for the real-time services. Therefore, effective interference management schemes are crucial for the evolution of any new wireless system such as the WINNER in order to maintain the error rate at a minimum level. In this paper, we propose an interference management scheme that uses coordination across *base station*s (BSs) in the interferer group, takes co-channel interference in consideration, and schedules and routes packet in such a way that dominant in-group interferers are avoided or minimized.

The idea of group-wise coordinated transmission scheduling using BS coordination in conventional cellular networks was first studied in [3]. In such a scheme, only one in-group BS transmits at any time in an orthogonal manner, while others in the group remain silent. However, the time-orthogonality in transmissions results in reduced spectral utilization with the benefit of improved interference situations. In [4], it has been shown that non-orthogonal scheduling, with possible concurrent transmissions from in-group BSs based on the channel states, attains better performance in terms of area spectral efficiency and packet delay. The idea of non-orthogonal scheme is that if the interference levels, and hence the *signal-to-interference-plus-noise ratios* (SINRs), are predicted and exchanged among in-group BSs, then every BS in the interferer group would potentially be able to transmit concurrently with its feasible transmission parameters in the presence of others as interferers. This, in contrast with proactive orthogonal scheme, achieves better spectral utilization. We extend the idea of non-orthogonal scheduling in a relay-based network.

A *fixed relay node* (FRN) uses narrow beamwidth directional receive antenna with high gain (see details in Section II & III) to receive data from the serving BS. Furthermore, the paths between the BS and FRN might include a *line of sight* (LOS) component. Therefore, the transmissions in the BS-FRN link are more robust. A *user terminal* (UT) receiving with omnidirectional antenna will experience dominant interference from front facing neighboring BSs as well as interference from surrounding FRNs. However, it should be noted that the interference from the BSs is much stronger than that from the FRNs, as BS transmit antenna is directional and it uses higher transmit power. Therefore, interference from BS and FRN should be treated differently. In particular, when a UT is receiving from

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its FRN, it should be protected from dominant BS interferers. To ensure this, in the proposed scheme, transmissions from in-group BSs and FRNs are partitioned in time. Detailed descriptions of the scheme are provided in Section III.

Although proposed scheme is equally applicable for uplink (with appropriate differences with regard to channel prediction locations, control signal and data directions), for the illustration purposes, we limit our discussions to downlink transmissions only.

The WINNER system is envisioned to use *multiple-input-multiple-output* (MIMO) with *orthogonal frequency division multiple access* (OFDMA). However, for the simplicity of illustrations, we consider *single-in-single-out* (SISO) antenna configuration in *time domain multiple access* (TDMA) system setup, as the benefits can be translated into the WINNER system easily.

The rest of this paper is organized as follows. Section II describes the system model, detailing the relay based network setup. We present descriptions of the scheme in Section III. Simulation models and parameters are provided in Section IV. We briefly discuss the complexity and feasibility issues of the proposed scheme in Section V. Simulation results are presented in Section VI followed by the conclusions in Section VII.

II. SYSTEM MODEL

We consider a network consisting of 3-sector cell sites as shown in Fig. 1. The available spectrum of 20 MHz in the 5 GHz band is equally divided and allocated to three sectors for the *frequency division duplex* (FDD) TMDA downlink. The sectors with identical shading intensity are the co-channel sectors. It should be noted that frequency allocation and antenna positioning in Fig. 1 are considered to form an example layout only in order to illustrate proposed interference aware scheduling scheme.

We further assume that every sector is equipped with a FRN in its centre in order to improve overall network coverage and/or capacity. A UT can receive downlink packets either directly from the BS or via the FRN, depending on the route quality. We have considered time-domain relaying [2], i.e. FRN-UT link uses same frequency resources as used by BS-FRN or BS-UT separated in time.

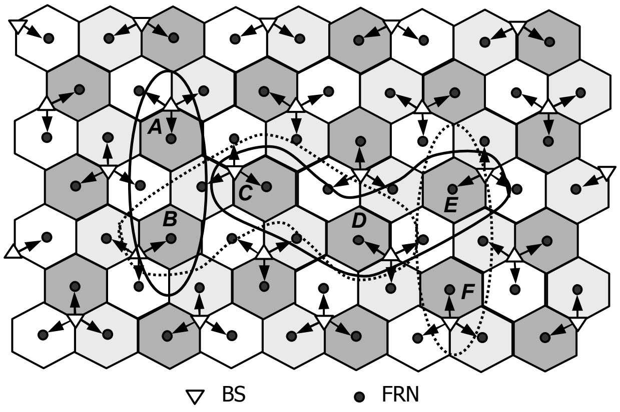

Fig. 1: Network consisting of 3-sector cell sites

The UT receive and FRN transmit antennas are omnidirectional with gains of 0 and 3 dBi, respectively, while sector transmit and FRN receive antennas are directional (patterns are defined in Section IV). The FRN receive antenna points to the associated sector antenna. We assume fixed transmission powers of 20 and 2 Watts at the sector and FRN, respectively.

We assume that UTs in the network belong to the same service class, having the same data rate requirements. Downlink packets generated for all UTs arrive at the BS queue, from where they are scheduled. The packet from the *head of the line* (HOL) of the queue is considered for scheduling in a *first-come-first-serve* (FCFS) basis. The proposed scheme looks at how these in-group HOL packets are scheduled and routed in order to avoid or minimize dominant interferers.

We also consider that the FRNs have the capability to decode the received packets. Any packet received erroneously at the FRN will be discarded.

III. DESCRIPTIONS OF THE SCHEME

As stated earlier, the time frame is partitioned into two sub-frames; one sub-frame is used for BS transmissions while the other is for FRN's. The proposed scheduling scheme finds a combination of concurrent in-group BS transmissions of the HOL packets in the first sub-frame as well as the transmission parameters for FRN-UT transmissions in the second sub-frame if routed through the FRN. The BSs and FRNs are the potential interferers for transmissions in the first and second sub-frames, respectively. The objective is to attain maximum possible spectral utilization for these packets, given the mutual interference at the FRNs and UTs.

Considering the darkest shaded sectors in Fig. 1, it is seen that downlink transmission from BS *A* would be the potential dominant interference for the UTs in BS *B*, due to relative locations and antenna directivities. Therefore, the questions are (1) *should BS B remain silent when BS A transmits*?, (2) *should BS B transmits and BS A remains silent as the intended UT in BS B might utilize the spectrum more efficiently*, and (3*) should BS A and B both transmit concurrently as the mutual interference might not be severe at the time of interest*? Making this kind of decision requires coordination between these two BSs.

The proposed scheme answers the above questions by choosing the best possible option from those mentioned above. For the above example, BSs *A* and *B* form an interferer group, exchange channel state information, and schedule and route their traffics in a coordinated fashion. With similar arguments, BSs *B*, *C*, and *D* should belong to another interferer group, as UTs in BS *C* receive potential dominant interference from BSs *B* and *D*. In a straightforward manner, we can see that BSs *C*, *D*, and *E* belong to a third interferer group, and BSs *E* and *F* to a fourth. A careful observation into the layout would reveal that this pattern of interferer groups would repeat in the layout for the given assumption of system parameters and frequency allocations. In this study, we simulate these four interferer groups as shown in Fig. 2 in order to evaluate the proposed

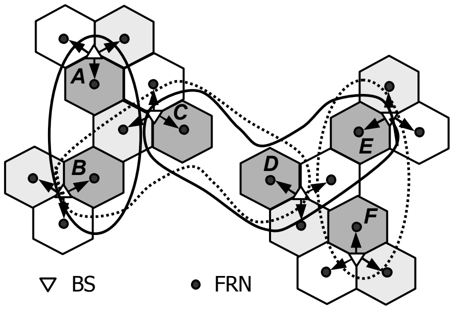

Fig. 2: Interferer groups $\{A, B\}$, $\{B, C, D\}$, $\{C, D, E\}$, and $\{E, F\}$ considering the darkest shaded co-channel sectors

interference management scheme. The performance of the scheme is compared with that of a reference scheme that does not use coordination.

It should be pointed out that a BS could be a member of different interferer groups. For instance, BS C in Fig. 2 is a member in group $\{B, C, D\}$ as well as in $\{C, D, E\}$. Each group makes scheduling decisions based on the in-group channel information. Therefore, a particular BS might receive two different commands from two different groups. In that case, the BS will follow the more conservative one in order to ensure that it is neither causing too much interference to the transmissions of other in-group transmissions nor receiving too much interference from other in-group BSs. For example, if BS C receives "do not transmit" from $\{B, C, D\}$ and "transmit with 16-QAM with coding rate of 3/4" from $\{C, D, E\}$, it will remain silent. If it receives "transmit" from both groups, it chooses the command with lower transmission parameters.

We assume that UTs and FRN in each BS monitor their channels from the serving BS as well as from interferer in-group BSs and FRNs. These channel states are reported back to the serving BS from where they are exchanged among in-group BSs via wireline backbone connections. Therefore, a BS knows how much interference its particular UT is receiving from other in-group interfering BSs and FRNs, as well as how much interference it and its FRN are causing to a particular UT in other in-group BSs. Based on this information, BS makes intelligent decision on not only when it should keep silent, but also what transmission parameters it should use and which route the BS should use for a packet to a particular UT, given different possibilities of concurrent in-group transmissions. Fig. 3 describes the steps for the proposed scheduling algorithm.

Step 1: Information reporting and exchange (every frame)
  1.1: *BS receives channel information from its FRN and UTs*
  1.2: *Information exchange takes place among in-group BSs*
Step 2: Group-wise scheduling and routing
  2.1: *HOL packets from in-group BS queues become candidates*
  2.2: *Scheduler finds combination of concurrent in-group transmissions and routes*
Step 3: Finalizing Scheduling and Routing Decisions
  3.1: *Resolution of commands at BS, if different*
  3.2: *Update frame usage time*
  3.3: *Repeat Steps 2 and 3 until the whole frame is scheduled*

Fig. 3: Scheduling algorithm

IV. SIMULATION MODELS AND PARAMETERS

The cell radius is considered to be 500 meters. The following exponential path-loss, L, model has been used [5],

$$L = 38.4 + 35.0\log_{10}(d), \qquad (1)$$

while free space path-loss has been used if the transmitter-receiver separation distance, d, is less than 50 meters.

The gain patterns for BS transmit and FRN receive antennas are considered as follows [5]:

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, 25\right] \text{ [dB]}, \qquad (2)$$

where the values of θ_{3dB} in (2) are 70^0 and 20^0 for the BS transmit and FRN receive antennas, respectively, and θ varies from 0 to 180^0.

The average noise power is calculated to be –130.59 dBW for the 6.67 MHz channel bandwidth and noise figure of 5 dB. We have considered independent lognormal random variables with a standard deviation of 8 dB for shadowing. Time-correlated flat fading with Doppler frequencies of 2 and 10 Hz have been considered for the FRNs and UTs, respectively, where the Doppler spectrum is rounded bell-shaped [6]. The fading on the desired BS-FRN link is Ricean with a K-factor of 0.5, while fading in other links including all interferer links are Rayleigh distributed.

Adaptive modulation and coding (AMC) is used with *bit interleaved coded modulation* (BICM) as shown in Table I. The modulation options listed in the table are the mandatory schemes available in the IEEE 802.16a standard [7]. In selecting AMC modes for each link, a 3 dB margin has been considered to compensate for out-of-group interference in the proposed scheme (as well as in the reference scheme for fair comparison).

Real-time 2-*Interrupted Renewal Process* (2IRP) video traffic has been used to evaluate the performance of the proposed scheme. Two IRP sources are superimposed to model UT's video traffic as indicated in [8]. The UT downlink packet rate on average is 126.3 packets per second determined from parameters given in Table II. The size of packet is uniformly

TABLE I
LOOKUP TABLE FOR AMC MODES:
BICM WITH BIT ERROR RATE OF 1.0×10^{-4}

SINR Range (dB)	AMC Mode	Efficiency, η (Bits/Sec/Hz)
$3.39 \le \gamma < 5.12$	QPSK rate 1/2	1.0
$5.12 \le \gamma < 6.02$	QPSK rate 2/3	1.33
$6.02 \le \gamma < 7.78$	QPSK rate 3/4	1.5
$7.78 \le \gamma < 9.23$	QPSK rate 7/8	1.75
$9.23 \le \gamma < 11.36$	16-QAM rate 1/2	2.0
$11.36 \le \gamma < 12.50$	16-QAM rate 2/3	2.67
$12.5 \le \gamma < 14.21$	16-QAM rate 3/4	3.0
$14.21 \le \gamma < 16.78$	16-QAM rate 7/8	3.5
$16.78 \le \gamma < 18.16$	64-QAM rate 2/3	4.0
$18.16 \le \gamma < 20.13$	64-QAM rate 3/4	4.5
$20.13 \le \gamma < 24.30$	64-QAM rate 7/8	5.25
$\gamma \ge 24.30$	64-QAM rate 1	6.0

distributed between 250 to 550 bytes giving average data rate of 404.16 kbps per UT.

The summation of queuing delay and packet transmission delay gives end-to-end packet delay. Packet transmission delay is determined from the packet size L_p, symbol rate of the transmission channel r_s, modulation level M, and coding rate r_c as expressed below:

$$t_d = \frac{L_p}{r_s r_c \log_2 M}. \tag{3}$$

The interferers may arrive or leave anytime during the transmission time of a packet of interest. Therefore, the SINR varies at different segments of the packet during the transmission time, and packet experiences different bit-error rates at these segments. The number of erroneous bits in any segment s is given by the product of the probability of the bit error in the segment of interest, $\Pr_{b(s)}$, and the number of bits resides in the segment, $N_{b(s)}$. The total number of erroneous bits in the packet, N_e, can be written by the following relation:

$$N_e = \sum_{s=1}^{S} \Pr_{b(s)} N_{b(s)}, \tag{4}$$

where S is the total number of segments in the packet of interest experiencing different SINR.

The number of erroneous bits in a received packet is used to decide if the packet is in error. In particular, we assume that a received packet is in error if more than 1% of the total bits in the packet are erroneous. We have not considered retransmissions of erroneous packets by ARQ.

We have considered the TDMA frame length to be 5 ms. Packets are scheduled in a frame-by-frame basis at the start of every frame. The frames in different in-group BSs are synchronized in the proposed coordinated scheme, while they are unsynchronized in the uncoordinated scheme. Any packet arrives at the current frame duration will have to wait at least until the start of next frame.

OPNET [9] Modeler with Wireless Module has been used to carry out event-based real-time simulations for this study. The default transceiver pipeline stages of OPNET models have been modified in order to include required path-loss model, fading, shadowing, and other simulation parameters considered in this study. For reference, the simulation parameters used in this study are summarized in Table III.

TABLE II
TRAFFIC MODEL PARAMETERS OF THE 2IRP VIDEO SOURCE [8]

IRP	Packet Arrival Rate (packets/sec)	Pareto Parameter for ON Distribution	Pareto Parameter for OFF Distribution
IRP1	112.38	1.14	1.22
IRP2	154.75	1.54	1.28

TABLE III
SYSTEM PARAMETERS

Parameters	Values
Three-sectored cell radius (m)	500
Propagation exponent, n	3.5
Fixed transmit power (Watts)	20 (BS) and 2 (FRN)
Transmission direction	Downlink
Uplink-downlink duplexing	FDD
Multiple access	TDMA
Frequency reuse factor	1/3
Carrier frequency, f (GHz)	5
Channel bandwidth, B (MHz)	6.67
Time correlated Rayleigh fading: max. Doppler freq., f_m (Hz)	2 (FRN) and 10 (UT)
Independent lognormal shadowing: standard deviation (dB)	8.0
Noise power, P_N (dBW)	-130.59
Frame length (ms)	5
Average data rate per UT (kbps)	404.16
Simulation tool used	OPNET Modeler 9.1 [9]

V. COMPLEXITY ISSUES

In order to facilitate adaptive transmissions, channel prediction is needed in any systems, however, the additional complexity in our scheme is to exchange this information among in-group BSs. This can be regarded as transferring interference management burden to the backbone high data rate connection such as fiber links. Another issue is the frequency of the channel reporting and exchange. In our simulations, we have considered a frame duration as channel reporting and information exchange interval. For fixed relay and low mobility UTs, the channel coherent time is long, even with TDMA access, and the channel information reporting is feasible with a reasonably large interval. However, for OFDMA channels, channel prediction and exchange would be feasible for UTs moving at vehicular speed with reasonable accuracy [10].

VI. SIMULATION RESULTS

Real-time simulations have been carried out in order to evaluate the performance of the proposed scheme by comparing essential network performance parameters such as *packet error rate*, *net throughput*, and *mean end-to-end packet delay*. The simulation time considered is long enough so that the observed parameters converge. The packet error rate is the ratio of the number of erroneous packets to the total packets received during the simulation period. The net throughput is expressed as correctly received packets per frame per sector. The mean end-to-end packet delay is the summation of queuing delay at the BS and the transmission time(s). These performance parameters are the functions of network loading. In our simulations, we have considered 4 to 22 UTs per sector to observe the effects of loadings in obtained results.

The packet error rate performances of the coordinated and uncoordinated schemes are compared in Fig. 4. It has been observed that inter-cell coordination results in an improved packet error rate in the proposed scheme. The packet error rate in the coordinated scheme is due to the out-of-group interference as well as from occasional channel prediction errors. At the loading value of 4 UTs per sector, the error rate in the uncoordinated scheme is observed to be better. This is due to the fact that in order to make fair comparisons, the BSs in the uncoordinated scheme are considered unsynchronized with random frame start times. For a low loading, frames are partially filled, and transmissions have less chance to collide. On the other hand, frames are always synchronized in the coordinated scheme. We observe that at a loading value of 22 UTs per sector, the packet error rate in the uncoordinated scheme is around three times compared to that in the proposed scheme. Higher packet error rate not only reduces the net throughput, it also incurs additional delay and signaling overhead if ARQ is employed in the system. This situation is undesirable for any delay-sensitive service.

The obtained net throughput is presented in Fig. 5. Due to significant improvements in packet error rate, the coordinated scheme achieves upto 25% higher net throughput at higher network loading.

Fig. 6 illustrates mean end-to-end packet delay. Because of the restrictions in transmissions in the coordinated scheme, queue length grows and packet experiences high delay at 22 UTs per sector. However, the overall performance will be limited by the error rate at this loading value. It is observed that the proposed scheme shows similar (slight worse, but acceptable for video traffic) delay performance up to the loading level of 20 UTs per sector. We should note that if erroneous packets have to be retransmitted by the ARQ, it will incur more delay, and the proposed scheme may perform considerably better up to 20 UTs per sector. Readers are referred to [11] for a detailed discussion on packet delay in a system with ARQ.

VII. CONCLUSIONS

The benefits of inter-cell coordination in providing QoS in non-ARQ cellular fixed relay networks have been studied in this paper. The neighboring BSs form interferer group, and exchange link state information with each other. This information is used to take intelligent group-wise scheduling and routing decisions in order to avoid or minimize in-group dominant interferers.

The performance of the scheme is compared with that of an uncoordinated scheme. It has been observed that the proposed scheme achieves up to three times better packet error rate and 25% higher net throughput, with acceptable mean end-to-end packet delay. If upper layers permit 10% packet error rate in the non-ARQ system, an uncoordinated scheme supports only around 4 UTs per sector while the proposed scheme with inter-cell coordination can accommodate up to 20 UTs per sector with acceptable mean end-to-end packet delay.

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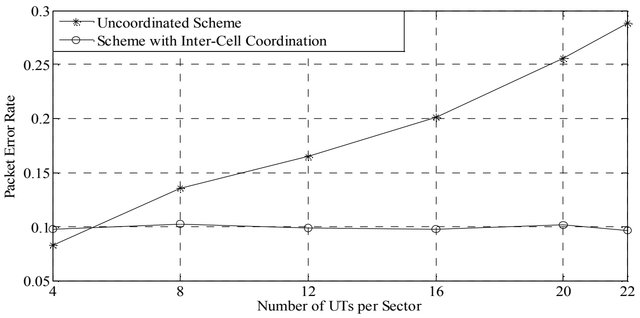

Fig. 4: Packet error rate

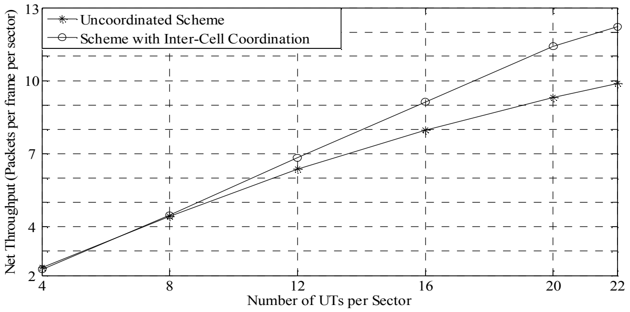

Fig. 5: Net throughput

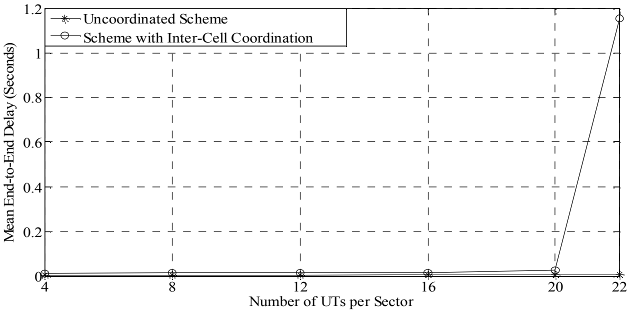

Fig. 6: Mean end-to-end packet delay