Macro diversity for Multicast transmission in high-speed cellular networks

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Dans ce papier, nous étudions l'ordonnancement de flux sur voie radio en mode *multicast*, alternative intéressante du mode *unicast* classique pour des données destinées à plusieurs utilisateurs. Le mode multicast implique qu'un paquet est envoyé en même temps à plusieurs terminaux d'une même cellule. Nous considérons la technique de macro-diversité dite sélective, consistant à transmettre les mêmes informations par plusieurs stations de base et, pour le terminal, à sélectionner le bloc de données reçu avec le plus fort signal. Nous développons un modèle analytique de calcul de débits moyens pour le *multicast* et l'*unicast*. Nous utilisons un ordonnanceur qui sert les terminaux selon la qualité instantanée du canal radio. Dans ce contexte, nous proposons un groupage efficace des mobiles en se basant sur la qualité moyenne de leurs canaux. L'étude montre que la macro-diversité sélective améliore les performances du multicast.

Keywords: ordonnancement multicast, macro diversité

1 Introduction

Packet scheduling is the functionality that distributes radio resources between users. Intensive research has been conducted on the performance of unicast schedulers in cellular networks (*e.g.* [ea06], [eA03]). During a service session, users may experience different channel conditions from a Transmission Time Interval (TTI) to another. The packet scheduler uses the reported channel qualities and chooses at each TTI the user to serve with the suitable modulation and coding scheme.

Multicast services have drawn a lot of attention for a few years. MBMS (Multimedia Broadcast/Multicast Service) is currently specified by 3GPP. However, the focus is on the access and core network rather then on the radio interface. The conventional way to manage multicast services on the latter interface is to duplicate transmissions to the User Equipments (UEs) over different TTIs. This may however considerably waste radio resource. In this paper, such an approach is called multiple-unicast. An interesting alternative is to really send a packet to several users. In order to avoid packet losses, the multicast scheduler must adapt the transmission bitrate to the mobile that has the lowest Signal to Noise Ratio (SNR). Other multicast schedulers are proposed in [WCea07]. However, packet losses with these schemes may be frequent. In a previous paper [EHL08], we have studied multicast and multiple-unicast for several users in the same cell. It was shown that multicast outperforms multiple-unicast only when the average SNR of the users is high. The main reason is that multicast scheduling has to consider the worst SNR as opposed to multiple-unicast scheduler that can choose at each TTI the user that has the best SNR. Users with low SNR are generally on the cell border and may generally receive several base stations (BSs). In order to increase the overall received SNR, macro diversity combining seems attractive. With this technique, the receiver may combine replicas of the same flow that has been transmitted by the neighboring cells. We consider the Selective Combining (SC) where a UE selects the signal with the highest SNR.

Our objective is then to quantify the gain of applying SC to multicast scheduling. Our multicast scheduler is called the equal-bitrate scheduler ; it is based on a new clustering strategy. Clustering is the way to define sub-groups of users receiving the same service. We have developed it for a single cell case in [HL08] but it will be explained here again for the sake of clarity.

This paper is organized as follows. In Section 2, the system model and assumptions are given. Section 3 explains the proposed equal-bitrate scheduler in a macro diversity context. In Section 4, we define the new clustering strategy. Section 5 gives the simulation results. Conclusions are drawn in Section 6.

2 Model description

In a regular cellular network, each cell has 6 neighboring cells. In a first approach, a cell may be divided in 6 sectors, each of which having one serving base station and one neighboring one. We restrict our study to one sector. Let BS1 be the serving base station and BS2 the neighboring one. We consider N users that are randomly distributed in the studied sector and listening to BS1 and BS2. Large-scale mobility aspects and time constraints are not considered. Let $\gamma_{s,i,j}$ be the SNR of signal received by UE i from BS s within cluster j and $\overline{\gamma_{s,i,j}}$ its average value. Due to channel variations, $\gamma_{s,i,j}$ are identical and independent distribution (iid) variables that change randomly from one TTI to another. The SNR is assumed to be constant during a TTI. Let γ_{ij} be the instantaneous SNR of user i, which is member of cluster j. We denote G as the number of clusters, S_j^g the size of cluster j and R_j the mean bitrate of cluster j. According to selective combining, each user i selects the data block with the maximum received SNR, we have then

$$\gamma_{i,j} = \max_{s=1..S} \gamma_{s,i,j} \tag{1}$$

where S is the number of BSs received by a user (in the framework of this study $S = 2$). Let $P_X(x)$ be the cumulative distribution function (CDF) of a random variable X. Similarly, $p_X(x)$ denotes the probability distribution function (PDF) of X. The CDF of $\gamma_{i,j}$ is given by

$$P_{\gamma_{i,j}}(x) = \prod_{s=1}^{S} P_{\gamma_{s,i,j}}(x). \tag{2}$$

Let γ_j be the selected SNR for cluster j. As a conservative approach is adopted, we have

$$\gamma_j = \min_{i=1..S_j^g} \gamma_{i,j}(t) \tag{3}$$

and the CDF of γ_j is equal to

$$P_{\gamma_j}(x) = 1 - \prod_{i=1}^{S_j^g} \left(1 - P_{\gamma_{i,j}}(x)\right). \tag{4}$$

Assuming the BS is serving user UE$_i$, we define β_{ij} as the largest transport block size (TBS) supported by UE$_i$. Let g be the function that relates β_{ij} to the reported γ_{ij} of the served user i, hence

$$\beta_{ij} = g(\gamma_{ij}). \tag{5}$$

It is easy to see that g is a strictly increasing function. Let h be the associated inverse function : $\gamma_{ij} = h(\beta_{ij})$.

3 Use of selective combining with multicast scheduling

In this study, we propose a scheduling scheme called the equal-bitrate scheduler. It aims at increasing fairness among multicast clusters while offering good system throughput.

3.1 Proposed user scheduling

Equal-bitrate scheduling is performed in two steps. First, the scheduler determines the convenient transmission bitrate for each cluster. The intra-cluster bitrate allocation strategy is conservative. Once the bitrate of each cluster is determined, the scheduler chooses the cluster to serve. In order to maximize the global throughput, a natural solution is to serve the cluster having the highest bitrate capacity. However, the scheduling must guarantee fairness between clusters. This may be achieved by realizing the same average bitrate for all the clusters. For this purpose, we define fairness factors $M_{j=1..G}$ such that the scheduler serves the cluster having a higher bitrate capacity with a lower probability, *i.e.* time is not uniformly shared between clusters. At instant t, cluster j is served if the product of its instantaneous SNR and its corresponding fairness factor M_j is the highest among all the clusters ; hence, if and only if

$$\gamma_j M_j = \max_{l=1..G} (\gamma_l M_l). \tag{6}$$

It can be established that the mean bitrate used to serve cluster j is

$$R_j = \frac{1}{D_{TTI}} \int_0^\infty \left[p_{\gamma_j}(x) g(x) \prod_{l=1, l\neq j}^{G} P_{\gamma_l}(\frac{xM_j}{M_l}) \right] dx \tag{7}$$

where D_{TTI} is the TTI duration. Equation 7 gives a general formula for the average bitrate per cluster j once the clusters are made. Note that this formula depends on $\{M_j\}$. The value of $\{M_j\}_{j=1..G}$ is fixed so that $\forall(i,j)\ R_i = R_j$. The value of G is determined by the clustering scheme which will be detailed later.

3.2 Application to a generic system

In [KH95], Knopp and Humblet have proposed a reference radio channel model based on an exponential distribution for γ. Hence :

$$P_\gamma(x) = 1 - \exp(-x/\gamma) \tag{8}$$

Combining equations 2, 4 and 8, we can set :

$$P_{\gamma_j}(x) = 1 - \prod_{i=1}^{S_j^g} \left(1 - \prod_{s=1}^{S} (1 - \exp(\frac{-x}{\overline{\gamma_{s,i,j}}})) \right) \tag{9}$$

In the case of pure multicast (G=1), the mean bitrate can be derived after a few computation

$$R_{mcast} = \frac{1}{D_{TTI}} . \int_0^\infty \prod_{i=1}^{N} \left(1 - \prod_{s=1}^{2} [1 - \exp \frac{-h(x)}{\overline{\gamma_{s,i}}}] \right) dx. \tag{10}$$

Function g is given by Shannon formula [Sha48] : $g(\gamma_i) = W D_{TTI} \log_2(1+\gamma_i)$ where W is the available bandwidth. Function h is then $h(x) = 2^{x/WD_{TTI}} - 1$.

4 Proposed clustering strategy

We propose a new clustering method called *mixed clustering* ; it combines multicast and unicast schemes according to the user's average channel conditions. We have seen in [EHL08] that multicast outperforms multiple-unicast only for high average SNRs (above around 3.7 dB). Our clustering scheme is then deduced as follows :

- An average SNR threshold is fixed so that the system can differentiate users. The average SNR is declared as "low" if it is below a threshold value denoted as $\overline{\gamma}_{thres}$. Let N_{low} be the number of users having a low average SNR.
- Users with low average SNRs have to be separated from each other. In fact, if the cluster size increases for low SNR values, the instantaneous bitrate capacity within the cluster becomes lower as the multicast strategy is conservative. Our solution is to serve these users according to a unicast scheme.
- Users with high average SNRs should follow a multicast scheme. They are grouped in the same cluster which contains $N - N_{low}$ users. Consequently, the resulting number of clusters G is equal to $N_{low}+1$. Of course, if all users have low average channel quality, G is equal to N_{low}.

5 Simulation results

We perform 100 iterations with different user distributions. Only one multicast service is considered. We evaluate results for 5 and 10 randomly distributed users located in cell 1 and listening to BS1 and BS2 (S=2). As we restrict ourselves to one service and one cell, these numbers remain reasonable. We compute the gain for pure multicasting, multiple-unicast and mixed multicasting. In the case of mixed multicasting, we fix the $\overline{\gamma}_{thres}$ to 3.7 dB as found in [EHL08]. Results of the average bitrate performance with the 95% confidence intervals are depicted in Table 1 for D_{TTI} = 2ms and W = 5MHz.

We see that macro diversity using SC improves the system performance. Gains for pure multicasting are of 20% and 18% for 5 and 10 UEs, respectively. In fact, the performance of this scheme depends only on

TAB. 1: Throughput (bps) with confidence intervals for different clustering strategies with/without SC

Strategy	N	without SC	with SC	SC Gain
Pure multicast	5 UEs	$4.30\ 10^6 \pm 4.6\%$	$5.16\ 10^6 \pm 4.8\%$	20%
	10 UEs	$3.40\ 10^6 \pm 6\%$	$4.01\ 10^6 \pm 5.8\%$	18%
Multiple-unicast	5 UEs	$3.49\ 10^6 \pm 3\%$	$3.24\ 10^6 \pm 3.4\%$	7%
	10 UEs	$2.5010^6 \pm 5\%$	$2.63\ 10^6 \pm 5.1\%$	5.5%
Mixed strategy	5 UEs	$5.12\ 10^6 \pm 4.7\%$	$5.58\ 10^6 \pm 4.6\%$	9%
	10 UEs	$4.23\ 10^6 \pm 6\%$	$4.54\ 10^6 \pm 6\%$	7.4%

the lowest SNR value ; as the SC technique increases the channel quality particularily for users at the cell border (*i.e.* having the lowest SNR), it has a direct impact on the pure multicast scheduler. In the case of mixed clustering and multiple-unicast, the gain is lower (9% and 7%, resp. for 5 UEs and 7.4% and 5.5%, resp. for 10 UEs). In fact, users with the lowest SNRs are served in a unicast scheme and increasing their average channel quality allows a better bitrate capacity for these users, the impact on the global system is less visible. SC allows users with higher SNRs to be served more frequently as the deviation between the lowest and the highest average SNR is cut off.

6 Conclusion

In this study, we consider macro diversity in the framework of multicast scheduling over high-speed networks. We have developed an analytical model for the mean bitrate calculations in order to evaluate the resulting scheduling performance. To ensure an optimal usage of our scheduler, we have used a clustering strategy that classifies terminals according to their average channel quality. We have shown that macro diversity using selective combining improves the system performance.

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