Traffic Split Scheme Based on Common Radio Resource Management in an Integrated LTE and HSDPA Networks

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***Abstract*—The future wireless communication networks will integrate different radio access technologies (RATs), which are referred to as heterogeneous wireless networks (HWNs). In this paper, we deal with two data oriented access networks, the Long Term Evolution (LTE) and the high speed downlink packet access (HSDPA). Assuming that the networks can support multi-homing access and the user can be served by both networks simultaneously, we propose a traffic split scheme with the aim of maximizing the throughput based on common radio resource management (CRRM). The split ratio in the scheme is dynamically adjusted under the consideration of the user's channel quality and the network load. The simulation results show that the proposed scheme can improve the throughput, also reduce the delay of the networks compared with the scheme using the fixed split ratio.**

***Keywords*—heterogeneous wireless networks (HWNs); multi-homing access; traffic split; common radio resource management (CRRM)**

I. Introduction

In the future, the wireless communication networks can be visualized as the integration of different radio access technologies (RATs), which are referred to as heterogeneous wireless networks (HWNs). Different RATs have their advantages and limitations. The co-deployment can lead to larger capacity, lower cost and better quality of services (QoS). Hence it is probable that mobile users will want to simultaneously receive data across multiple RATs in order to make use of all available bandwidth, which is referred to as multi-homing access [1]. The common radio resource management (CRRM) [1] is proposed to jointly utilize the resources in the HWNs in an efficient manner. In CRRM, joint resource scheduling (JOSCH) is proposed to support multi-homing access. Joint load control (JOLDC) takes the load status of the networks and the channel state into account and helps JOSCH to split the traffic stream of the user into multiple streams transported over multi-RATs simultaneously.

The design of the traffic split scheme is one of the key problems to the performance of multi-homing access. In [2], the problem is defined and illustrated at the IP layer. Data stream should be split into multiple streams below application level. Otherwise, the user has to decide the number of connections in advance in order to figure out how many flows to split the traffic into. The cognitive convergence layer (CCL) below IP layer is introduced to combine 802.11 multi-RATs [3]. The authors in [4] present a link aggregation technique to maximize the aggregated throughput, proportional to the bandwidth of underlying links, and the integrated WiMAX and WiFi networks are considered. In [5], a traffic split scheme in the coexistence of WLANs and 3G cellular network is described. The traffic stream is split into two parts, the base part and the enhancement part. This would be a performance enhancement mode, which can provide users better reliability and QoS. The design of the traffic split scheme depends on the HWN structure and underlying links.

In this paper, we present the architecture of HWN coupling LTE and HSDPA networks. They can be integrated on media access control (MAC) layer due to their similar transmission protocol and both of them transmit data on a frame basis. The traffic split problem is described as an optimization problem with the aim of maximizing the throughput. Using the optimal solution, the ratios to split the traffic packets are presented in theory. However, they often fluctuate due to retransmission and link adaption. The major contribution of this paper is the proposal of a dynamic traffic split scheme. The split ratios can be dynamically adjusted according to the feedback on the load information of the networks and the channel qualities of users. In the presented study, we focus on splitting the packets, but the scheme is general and can be applied to splitting the traffic flow.

The remainder of this paper is organized as follows: Section II describes the system model and the basic assumptions for the integrated LTE and HSDPA networks. In section III, the traffic split problem is formulated and resolved. Section IV presents the traffic split scheme. The simulations are carried out to evaluate the performance of the proposed scheme in Section V. Finally, conclusions are stated in Section VI.

II. System Model

As discussed in [7] , there are two different ways of designing an integrated LTE and HSDPA network architecture as shown in Fig. 1. One of them is that both the networks can connect to the core network (CN) and are finally coupled by the Packet Data Network (PDN) gateway. The other one is that both the networks are integrated in the radio access network (RAN) and connect to the CN by a single link. Referring to

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the architectures in [8], they are defined as loose coupling and tight coupling. The disadvantage of the former is the lack of load information from each RAT, which limits the possibility of load balancing. However, the latter can exploit the load status and channel quality at the expense of more complexity than the former. In this paper, four basic assumptions for the considered HWNs are listed here.

1) The tight coupling architecture is adopted. The CRRM function works on MAC layer, which maintaining good latency performance when relying on the use of LTE uplink with 1ms transmission time interval (TTI).
2) HSDPA NodeB and LTE eNodeB are co-located. They can exchange information of the networks on MAC layer. The delay of the exchange process is ignored.
3) Mobile users support multi-homing access. The traffic can be split and transmitted to the user over both RATs at the same time.
4) JOSCH and JOLDC can be achieved by CRRM function working on MAC layer.

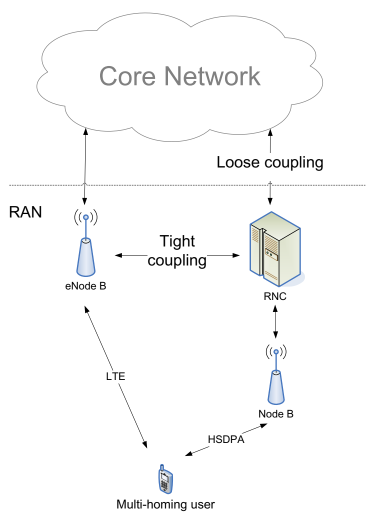

Fig. 1. Integrated LTE and HSDPA networks

A. Channel Rate Model

Both LTE and HSDPA adopt adaptive modulation and coding (AMC) in the downlink. The maximum number of bits per symbol (per Hz), denoted by $c_{m,n}(t)$, that resource m for user n can transmit per unit time during time slot t can be expressed as a function of SINR and target bit error rate (BER). Resource m represents a subcarrier in LTE or a time scale in HSDPA. There are several approximations for this function (e.g. [9]), which all of them are upper bounded by the following capacity expression [10]

$$c_{m,n}(t) = \lfloor \log(1 + \frac{-1.5}{\ln(5P_{ber})}\gamma_{m,n}(t)) \rfloor \quad (1)$$

where P_{ber} is the target BER and $\gamma_{m,n}(t)$ is the instantaneous SINR at time slot t for resource m corresponding to user n and $\lfloor a \rfloor$ means the largest integer smaller than a.

If C denotes the maximum modulation level available, the SINR can be partitioned into $C+1$ consecutive nonoverlapping intervals with boundary points denoted by Γ_c $(c = 0, 1, ..., C)$. Using (1), these boundary points can be obtained as follows,

$$\Gamma_c = \frac{(2^c - 1)\ln(5P_{ber})}{-1.5} \quad (2)$$

When the instantaneous SINR, $\gamma_{m,n}$, satisfies $\Gamma_c \leqslant \gamma_{m,n} \leqslant \Gamma_{c+1}$, the modulation level c is applied. Note that no packet will be transmitted if the modulation level is zero, that is c is zero.

B. Scheduling Model

JOSCH needs two level scheduling. The first level is the joint scheduler, and the second level is the resource scheduling controlled by the resource schedulers. LTE eNodeB and HSDPA NodeB have their resource scheduler respectively. In the first level, if the user requires multi-homing access, the incoming packet of the user will be split into sub-packets and assigned to the second level. The resource scheduler schedules the resource to the given user by resource scheduling strategy, such as round robin (RR) or proportional fair (PF). In this paper, RR scheduling is adopted in both systems. The average transmission rate $\overline{r}$ of the user, in the duration of t time scales, can be represented as

$$\overline{r} = \sum_{j=1}^{t} c_j^{'}/t = \overline{c} \cdot Tserv \quad (3)$$

$c_j^{'}$ is the number of bits transmitted in time scale j. If the user is not allocated resources, $c_j^{'}$ will be zero. Otherwise, $c_j^{'}$ will be decided by AMC. Then $\overline{c}$ represents the average of $c_j^{'}$ in the time scales when the user is allocated resources. The amount of these time scales is $Tserv$, which depends on the scheduling strategy. Meanwhile, the amount of resources for each user is fixed when the user is scheduled. For RR scheduling, we have

$$Tserv = [\frac{\widetilde{M}}{M}, 1]^{-} \cdot t \quad (4)$$

where $[a, b]^{-}$ means the minimum of a, b. $\widetilde{M}$ is the amount of users which can be allocated resources in each scheduling time scale. M is the number of users in the scheduling queue. Because each user is allocated fixed number of resources in each time, $\widetilde{M}$ will be larger than M, when the system is under loaded.

III. Formulation of Traffic Split

In this section, the traffic split problem in the considered heterogenous networks is formulated. For each user, the packet can be split into sub-packets and transported to the user over multi-RATs at the same time. However, in the need of decoding, the user has to wait until all the sub-packets are received.

The total throughput of the user depends on the transmitting time of the last sub-packet. The problem can be formulated as follows,

$$\text{maximize} \quad N \tag{5a}$$

$$\text{subject to} \quad \sum_{i=1}^{N} \max(t_i^L, t_i^H) \leqslant T \tag{5b}$$

$$0 \leqslant t_i^L \leqslant T,\ 0 \leqslant t_i^H \leqslant T \tag{5c}$$

$$\sum_{j=1}^{t_i^L} c{'}_j^L + \sum_{j=1}^{t_i^H} c{'}_j^H = P_i \quad i = 1, \cdots, N \tag{5d}$$

where N is the number of packets transmitted in the duration of T time scales, t_i^L and t_i^H represent the transmitting time for sub-packets of packet i in LTE and HSDPA respectively. Note that (5d) describes the transmission process and forms the boundary. $c{'}_j^L$, $c{'}_j^H$ are the number of bits transmitted in the time scale j for LTE and HSDPA. P_i is the amount size of packet i in bits.

To make this problem tractable, we reformulate it in a different way. There is no link between the transmitting time of two packets. Therefore, to achieve the maximum number of packets, the transmitting time for each packet has to be minimized, which can be obtained by maximizing the inverse of the transmitting time. Finally, using (3), the above problem can be reformulated as

$$\text{maximize} \quad G = \frac{1}{\max(t_i^L, t_i^H)} \tag{6a}$$

$$\text{subject to} \quad 0 \leqslant t_i^L \leqslant T,\ 0 \leqslant t_i^H \leqslant T \tag{6b}$$

$$L:\ \overline{r}^L \cdot t_i^L + \overline{r}^H \cdot t_i^H = P_i \tag{6c}$$

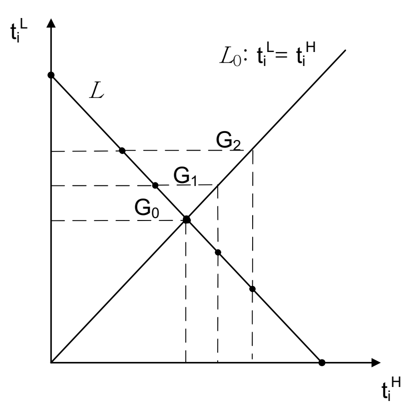

Fig. 2. Optimization problem of G

The solution can be achieved by using graphic shown in Fig.2. The dash lines are the contours of the problem object (6a). When the dash line moves right, the value of the object decreases (e.g. $G_0 > G_1 > G_2$). Under the constraint (6c), the solution must be on the line L. Therefore, the solution is obtained when the dash line has only one cross point with line L. In that case, the solution is on the line $L_0 : t_i^H = t_i^L$. The sub-packet transmitting time should be equal for both LTE and HSDPA networks. It is that minimizing the delay ($\Delta = |t_i^H - t_i^L|$) between both networks means maximizing the throughput.

IV. Traffic Split Scheme

Assume that packet P_i can be split into two parts, P_i^L for LTE and P_i^H for HSDPA. Due to the equal sub-packet transmitting time, we have

$$\frac{P_i^L}{\overline{r}^L} = \frac{P_i^H}{\overline{r}^H} \tag{7}$$

R, S_i^L and S_i^H are defined as the ratio of the sub-packets and the split ratios. Because S_i^L and S_i^H should be in proportions to the sub-packets, using (3) and (7), their relationship can be presented as follows,

$$\begin{aligned} R &= \frac{S_i^L}{S_i^H} = \frac{P_i^L}{P_i^H} = \frac{\overline{r}^L}{\overline{r}^H} \\ &= \frac{\overline{c}^L \cdot Tserv_L}{\overline{c}^H \cdot Tserv_H} \end{aligned} \tag{8}$$

where $Tserv_L$ and $Tserv_H$ are the time that user has been allocated resources. As described in (4), we have

$$Tserv_L = [\frac{\widetilde{M_L}}{M_L}, 1]^- \cdot t \tag{9}$$

$$Tserv_H = [\frac{\widetilde{M_H}}{M_H}, 1]^- \cdot t \tag{10}$$

where $\widetilde{M_L}$, $\widetilde{M_H}$ are the amount of users that networks can assign resources to in each scheduling time scale. M_L, M_H are the number of users waiting in the scheduling queue, which describe the network load status. Because of $S_i^L + S_i^H = 1$, the split ratios are given by

$$\begin{aligned} S_i^L &= \frac{R}{1+R} \\ S_i^H &= \frac{1}{1+R} \end{aligned} \tag{11}$$

However, in the practical networks, R can not be just configured as mentioned in (8). The channel quality varies over time due to various causes such as interference, multipath propagation, and terminal mobility. It is difficult to get the accurate value of $\overline{c}^L$, $\overline{c}^H$. Moreover, if channel quality is bad, hybrid automatic repeat request (HARQ) will increase, and transmission rate has to decrease to reduce error rates. The value of R often fluctuates, which makes the split ratios inaccurate. The delay Δ between LTE and HSDPA becomes larger and affects the performance of throughput. Motivated by these observations, a delay threshold δ is set to limit the fluctuation.

For the n-th packet, the value of $R(n)$ is set as follows,

$$R(n) = \begin{cases} \sqrt{\frac{t_{n-1}^H}{t_{n-1}^L} \cdot R(n-1) \cdot R'(n)} & , \quad \Delta \geqslant \delta \\ R(n-1) & , \quad \Delta < \delta \end{cases} \tag{12}$$

where t_{n-1}^H and t_{n-1}^L are the transmitting time for the $(n-1)$-th sub-packet in HSDPA and LTE, and $R'(n)$ is the prediction ratio calculated by (8). If the delay Δ is larger than the threshold δ, the ratio of the new sub-packets $R(n)$ will be updated under the consideration of three factors, the transmitting time and the ratio of the last sub-packets and the prediction ratio. In fact, $\frac{t_{n-1}^H}{t_{n-1}^L} \cdot R(n-1)$ is the ratio of the average transmission rate of the last sub-packets. The square root function is used to decrease the fluctuation of $R(n)$. The procedure of the traffic split scheme is described as follows

Step 1) Initialization phase. The joint scheduler receives the new call request from the multi-homing user. According to the user's channel quality indicator (CQI) and the load status, the joint scheduler calculates the initial value of R and the split ratios S_i^L, S_i^H for the user.

Step 2) Transmission and feedback. The packet is split according to the split ratios. The two sub-packets are added to the scheduling queues in the HSDPA scheduler and LTE scheduler, and transmitted to the user separately. When the transmission is finished, the transmitting time and load information are feedback to the joint scheduler as shown in Fig. 3.

Step 3) Updating ratios. The joint scheduler calculates the delay Δ. If Δ is greater than or equal to δ, the value of R for the next packet will be updated by the prediction ratio, the transmitting time and the ratio of the last packet. If Δ is less than δ, R is the same as that of the last packet. Then the split ratios is obtained using (11).

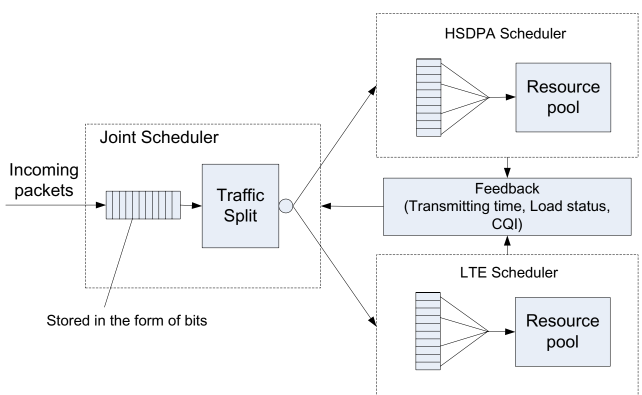

Fig. 3. Traffic split model

V. Simulation Results

In this section, the performance results of the proposed traffic split scheme with adjust ratio (AR) are presented. The scheme with fixed ratio (FR) (e.g. R=3:1, R=2:1) is shown for comparison. The performance measure of interest is the delay and the throughput. The general simulation parameters are given in Table I. HSDPA NodeB and LTE eNodeB are deployed in the same place. The LTE system has $N = 600$ available sub-carriers with DFT size of 1024, which means 50 resource blocks(RB). The HSDPA system uses 15 channelization codes with a spreading factor of 16. Multipath Rayleigh fading channels are considered, with each independent fading path generated by the Jakes Model [11].

The dynamic traffic model [12] [13] is adopted in the simulation. A new user arrives into the HWN with a finite-length file request, and leaves the HWN when the file is transmitted. Without loss of generality, each user is assumed to start a new transmission only after the old one is finished, and each new transmission by the same user is treated as a new user.

TABLE I
SIMULATION PARAMETERS

Parameter	Setting
Cellular model	7 cells, wrap-around
Inter-site distance	1000m
Min. dis. between UE and NodeB	35m
Maximum Tx power	43 dBm
Fast fading model	Rayleigh
Slow fading standard variance	8dB
HARQ model	Ideal chase-combing
Thermal noise density	-174dBm/Hz
UE noise figure	9 dB
Antenna model	MIMO 2x2
Delay threshold δ	15.0ms
MCS	QPSK (R=1/3,1/2,2/3,3/4) 16QAM (R=1/3,1/2,3/4,4/5) 64QAM (R=3/5, 2/3, 4/5)
HSDPA	**Setting**
Bandwidth	5MHz
Spreading factor	16
Channelization codes	15
SubFrame length	2ms
LTE	**Setting**
Bandwidth	10MHz
SubFrame legnth	1ms
Subcarrier spacing	15KHz
Number of RBs	50

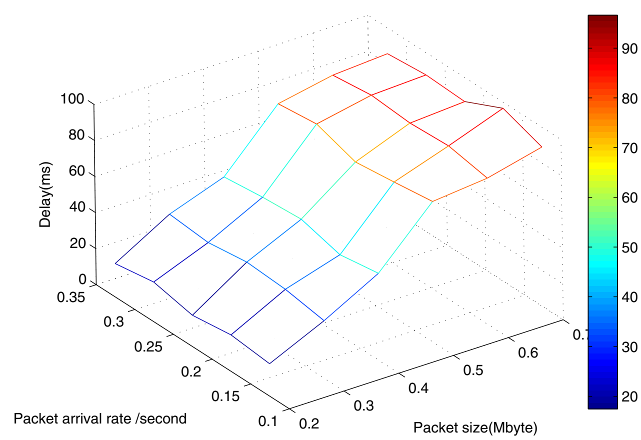

Fig. 4. Delay under varying packet arrival rate and packet size

A. Delay Analysis

Fig. 4 shows the relationship between the delay and the traffic model. The transmitting delay climbs along with the increasing packet size. The split ratios do not change during the

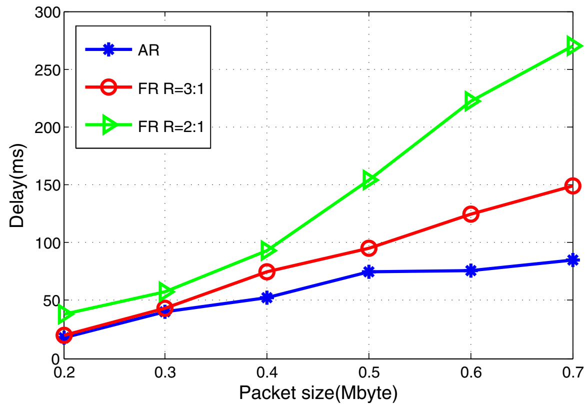

Fig. 5. Delay performance comparison of traffic split schemes with varying packet size

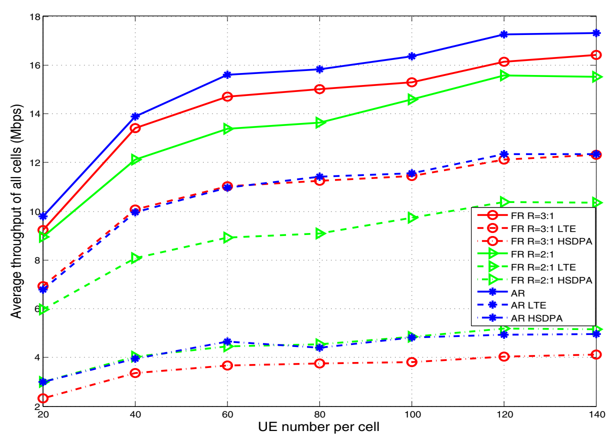

Fig. 6. Throughput performance comparison of traffic split schemes with the number of users

transmission of one packet. Both LTE and HSDPA networks need more time to transmit larger packets. The traffic load between them becomes more unbalanced with the increase in the packet size. However, the delay is insensitive to the packet arrival rate. This is due to that a new packet arrives only after the old one is finished. In the following simulations, the packet arrival rate is set at the value 0.2.

In Fig. 5, the delay of the two schemes is presented. The AR scheme performances better than the FR scheme. The delay of the FR scheme dramatically increases with the increasing packet size. The delay differences between the AR scheme and FR scheme become larger, especially when the packet size is more than 0.5 Mbytes. It illustrates that the AR scheme is suitable to transmit the large packets.

B. Throughput Analysis

The simulation results in Fig. 6 show the total throughput of AR and FR schemes with different number of users in the HWN. In this case the packet size is set at 0.5 Mbytes. The throughput of HWN is limited by the traffic load in each network. If the split ratio is unappropriate, one of the networks will be over loaded while the other one will be under loaded. The FR scheme with the ratio 2:1 dispatches too much traffic to HSDPA network, and that with the ratio 3:1 makes the LTE network over loaded. The traffic load balance is achieved by AR scheme with the adjust split ratio, which allows AR scheme obtain the better performance of throughput than the FR scheme.

VI. Conclusion

In this paper, the traffic split scheme based on CRRM is proposed in the integrated LTE and HSDPA networks. By resolving the traffic split problem, it is found that if we want to maximize the throughput, we have to minimize the transmission delay between both networks. To achieve this, the split ratios can be dynamically adjusted according to the channel qualities and the load status of the networks. Simulation results show that the proposed scheme provides better performance than the fixed ratio scheme. The margin between the delay of two schemes becomes larger with the increased packet size. The proposed scheme is suitable to transmit the large packets. What's more, the proposed scheme obtains the better performance of throughput by achieving the traffic load balance. Further study will focus on more diverse services in the integrated LTE and HSDPA networks.

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