http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 10 (1): 182-188, 2011
ISSN 1812-5638 / DOI: 10.3923/itj.2011.182.188

A Multi-radio Packet Scheduling Algorithm for Real-time Traffic in a Heterogeneous Wireless Network Environment

Yang Cui, Yubin Xu, Rongqing Xu and Xuejun Sha
Communication Research Center, Harbin Institute of Technology, Harbin, China

Abstract: The integration of heterogeneous wireless network has become an overwhelming tendency. So, it is a huge challenge for the network designers that how to manage resource in these access networks with different Radio Access Technologies (RATs) in a cooperative mode. As a feasible scheme, Generic Link Layer (GLL) is introduced. In this study, a novel multi-radio packet scheduling algorithm, is proposed for real-time traffic. There are four outstanding contributions in QU. First, in order to guarantee Quality of Service (QoS) of real-time traffic and avoid wasting resource, a scheduling utility function is developed to represent the degree of satisfaction of performing a packet scheduling in term of avoiding wasting resource provided that guaranteeing QoS. Second, using this utility function, a packet scheduling model, which in fact is a NP problem, is designed and analyzed based on joint consideration of fairness. Third, for improving execution rate, Hopfield Neural Network (HNN) is used to fast find an optimal solution for the scheduling model. Final, simulation is set up and is compared with M-LWDF and PLR algorithms to evaluate performance of QU algorithm. Simulation results show that under high load QU algorithm has lower packet loss ratio and higher spectrum efficiency while offers allowable average packet delay.

Key words: RAT, packet scheduling, GLL, utility function, neural network

INTRODUCTION

With the fast development of wireless communications technology and by the effect of industry interest, a large number of wireless access network are deployed in wireless access area. These networks use different Radio Access Technology (RATs) and have diverse coverage, such as WCDMA, CDMA200, TD-SCDMA, WiMAX and WLAN (Eshanta *et al*., 2009). So, in order to effectively utilize radio resource, how to interconnect and converge these heterogeneous wireless access networks has become an overwhelming tendency of network development. At the same time, the tendency provides the great and bright potential business opportunities for network operators. However, it also presents a huge challenge for the network designers to manage resource in these access networks with the different RATs in a cooperative way. In this context, one feasible solution is the introduction of GLL (Sach *et al*., 2004) that performs unified link-layer processing across different Radio Accesses (Ras) belonging to different wireless access networks. GLL is located between data link layer (layer 2) and network layer (layer 3) and it's main function is to efficiently allocate data flows from network layer to independent RAs based on Channel Quality Information (CQI) and QoS requirements. There is much literature in which, it is proved that utilization of multi-radio access can achieve more gains. Such as, Dimou *et al*. (2005) proposed a greedy algorithm which get gain of 15% in spectrum efficiency.

Future networks will adopt packet switching technology, especially IP switching, while circuit-switched scheme will be eliminated. For example, WiMAX (IEEE, 2006) and 3GPP Long Term Evolution (LTE, 2006) both are IP-based network. Therewith, heterogeneous wireless networks will use IP protocol and then IP-based real-time traffic, such as VoIP and video telephone, will become the major traffic. In the context, it is very important for guaranteeing QoS of real-time traffic that how to quickly and efficiently schedule IP data packets to independent RAs with different RATs. On one hand, spectrum is limited. On the other hand, wireless channel is time-varying. Under the action of these factors, the spectrum efficiency and execution time also should be considered into the design of scheduling algorithm. Many packet scheduling algorithms for real-time traffic in wireless system have been proposed in published literatures, for instance, M-LWDF (Andrews *et al*., 2001) and PLR (Liu *et al*., 2007). Unfortunately, none of them takes the above two factors into consideration.

In the light of analyses above, a novel multi-radio packet scheduling algorithm named QU is proposed for

Corresponding Author: Yang Cui, Communication Research Center, Harbin Institute of Technology, Harbin, China

real-time traffic. In QU algorithm, a suitable utility function is designed to represent the degree of satisfaction of performing a multi-radio access packet scheduling (i.e., choosing a user's packet and scheduling the packet to a RA) in relation to avoiding wasting resource provided that guaranteeing QoS. Using the utility function, a packet scheduling model is developed based on joint consideration of fairness, while the solution to the model is a NP problem. As is known, execution cycle of packet scheduling is in a time scale of milliseconds and performing time of packet scheduling algorithm must be smaller than it. As a feasible approach, HNN has some advantages which are available for solving this problem. HNN can be easily implemented on hardware circuit. By means of HNN on hardware, the optimal solution of the suspended problem can be solved in microsecond. In the light of advantages of HNN, it is used in QU algorithm. Simulation results show that, compared with M-LWDF and PLR algorithms, QU algorithm presents lower packet loss ratio and higher spectrum efficiency under high load.

SYSTEM DESCRIPTION

From the Fig. 1, it is shown that GLL is located between layer 2 and layer 3 and it's main function is to perform packet scheduling and translate data between IP network layer and access link layer or among access links with different RATs. In order to obtain more the multiuser and multiple access diversity gains, a multi-radio packet scheduling scheme is used in which integrates user selection and access link selection into one step. The major components of GLL are QoS classifiers, FIFO queues and packet scheduler and the working procedure of it is shown in Fig. 1. Firstly the data packets from IP layer are classified and moved into the corresponding queues; secondly, the scheduler selects user packets and allocates access links to them in accordance with scheduling criterion. For the sack of convenience in analysis, the case is used in this study that a user only generates one real-time traffic. In fact, the proposed algorithm is also applicable to the case that one user have multi-traffic.

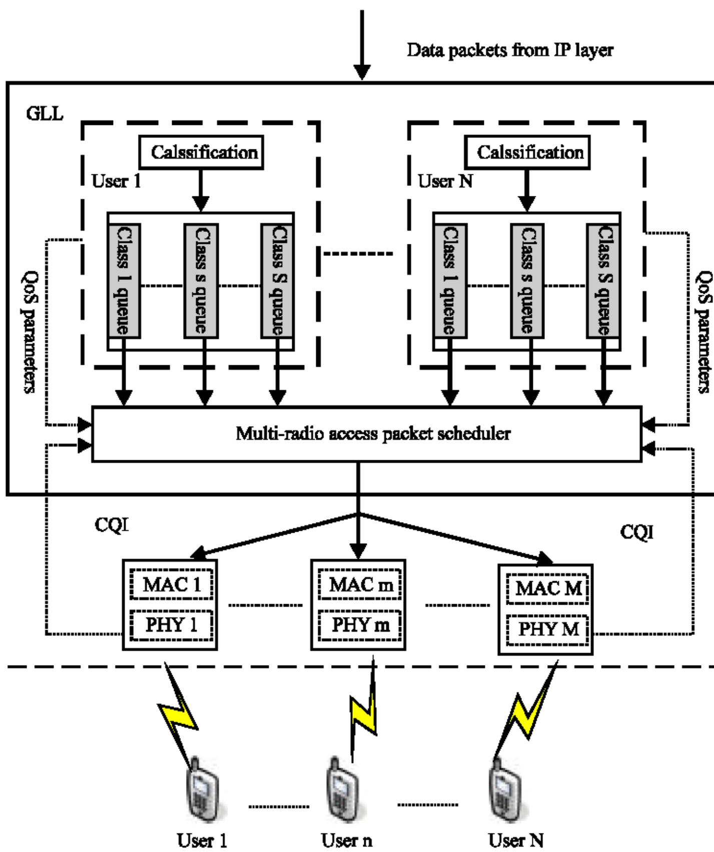

Fig. 1: The framework of multi-radio access packet scheduling

MULTI-RADIO PACKET SCHEDULING MODEL AND QU ALGORITHM

The section is mainly divided into three parts. First, scheduling utility function is introduced with target that avoid wasting resource provided that guaranteeing QoS; second, using this proposed utility function, a multi-radio packet scheduling mode is presented which is a NP problem; finally, QU algorithm is developed using HNN which is employed to fast and effectively solve NP problem.

Scheduling utility function: A utility function is presented to express the degree of satisfaction of performing a multi-radio packet scheduling in term of avoiding wasting resource provided that guaranteeing QoS. Delay is an important QoS parameter for real-time traffic. If the actual delay of a packet exceeds a threshold D, the packet will be discarded. Therefore, a utility function of scheduling, denoted as $U_{ij}(t)$, will increase monotonically with the actual packet delay $d_i(t)$ by following certain weight function $D_i(d_i(t))$, which will increase sharply when, $d_i(t)$ closes to threshold D_i. These subscripts i and j denote ith user and the jth RA, respectively. Based on analyses above, $D_i(d_i(t))$ is expressed as (Sang *et al*., 2007):

$$D_i(d_i(t)) = e^{d_i(t)/D_i} \tag{1}$$

On the principle that improving spectrum efficiency on the premise of guaranteeing users' QoS, scheduler has to schedule the packet to a RA which provides higher bit rate as much as possibly. In addition, packet should not be scheduled to a RA which provides the bit rate larger than the one that the packet actually demands for QoS guarantee. For clarity, some parameters should be defined. The minimum target bit rate $R_{mini}(t)$ is calculated as:

$$R_{mini}(t) = \frac{USD_i}{D_i - d_i(t)} \tag{2}$$

where, USD_i is the number of the remaining bit of the packet at head of a queue. For real-time traffic in wireless packet communication system, it is difficult to give accurate delay guarantee due to the time-varying characteristic of channels. But the QoS guarantee can be obtained in statistics. Andrews *et al.* (2001) developed a delay requirement of real-time traffic and defined it as follow:

$$P\{d_i > D_i\} \le \delta_i \tag{3}$$

Equation 3 means that the probability of exceeding D_i is not higher than δ_i. Among different methods, for real-time traffic, Effective Bandwidth Theory (EBT) is feasible approach to guarantee QoS from the view of statistics (Courcoubetis *et al*., 1994). EBT have been used in wired networks originally while actually EBT has the same availability in wireless networks for statistical analysis of real-time traffic' QoS. Assuming that in GLL a queue is allocated to every real-time traffic whose length equals to the product of the average bit rate and delay threshold, probability in Eq. 3 is converted to the probability of queue overflow. Real-time traffic is subordinate to a ON-OFF model, then the minimum bit rate $E_i(\delta_i)$ meeting Eq. 3 is presented as:

$$E_i(\delta_i) = m_i + \frac{\rho_i}{2B_i}\log(\frac{1}{\delta_i}) \tag{4}$$

where, m_i denotes the average bit rate of real-time traffic; δ_i and ρ_i are overflow probability and diffusion index, respectively. B_i is queue length. Then let, $R_{ij}(t)$ represent the bit rate with which jth RA provides ith user and $R_{maxi}(t)$ denote the maximum bit rate that ith user can obtain at the time t. $\overline{R_i(t)}$ is the average bit rate which ith user obtains in a certain period t_c and is expressed as (Jalali *et al*., 2000):

$$\overline{R_i(t)} = (1 - \frac{1}{t_c}) \cdot \overline{R_i(t-1)} + \frac{1}{t_c} \cdot R_{ij}(t) \cdot A_{ij}(t) \tag{5}$$

where, $A_{ij}(t)$ is RA allocation indicator, and $A_{ij}(t) = 1$ if jth RA is allocated to ith user; Otherwise, $V_{ij}(t) = 0$. For guaranteeing QoS, average rate $\overline{R_i(t)}$ during a certain period should equals to $E_i(\delta_i)$. Then denote $R_{Ei}(t)$ as the effective bit rate which makes $\overline{R_i(t)}$ equal to E_i at the time t. It is considered as wasting resource that scheduling a user packet to the RA which provides the bit rate larger than R_{Ei} and is not beneficial to improve spectrum efficiency when user number is large. $U_{ij}(t)$ increases monotonically with another weight function $RA_{ij}(R_{ij})$, which is determined by R_{ij}. Considering the above analysis $RA_{ij}(R_{ij})$ is defined as:

- **Condition 1:** $R_{mini} < R_{Ei} < R_{maxi}$

$$RA_{ij}(R_{ij}) = \frac{1}{1 + e^{-a_i(R_{ij} - b_i)}} \tag{6}$$

$$\text{Where } a = \frac{2\ln 10}{R_{Ei} - R_{mini}}, b = \frac{2}{R_{Ei} - R_{mini}}$$

- **Condition 2:** $R_{mini} \le R_{maxi} \le R_{Ei}$

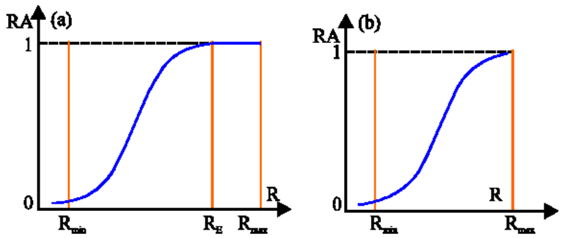

Fig. 2: (a, b) RA function curve

$$RA_{ij}(R_{ij}) = 1, \text{ only when } R_{ij} = R_{max\,i} \\ RA_{ij}(R_{ij}) = 0, \text{ otherwise} \tag{7}$$

- **Condition 3:** $R_{mini} < R_{maxi} < R_{Ei}$

$$RA_{ij}(R_{ij}) = \frac{1}{1+e^{-a_i(R_{ij}-b_i)}} \tag{8}$$

$$\text{Where } a = \frac{2\ln 10}{R_{max\,i} - R_{min\,i}}, b = \frac{2}{R_{max\,i} - R_{min\,i}}$$

The first condition implies that both R_{Ei} and R_{mini} can be satisfied for ith user. From the function curve shown in Fig. 2a, it is obvious that $RA_{ij}(R_{ij})$ increases sharply with R_{ij} if $R_{ij}>R_{mini}$, while becomes flat and approximately closes to 1 if $R_{ij}>R_{Ei}$. Because scheduler always aims at maximizing utility function, the design of the utility function can avoid allocating overmuch resource to these users whose QoSs have been satisfied. In addition, given the same resource, it is helpful to provide more users with QoS-guaranteed service. Therefore, when the number of users is high, the good throughput can be increased through decreasing packet loss ratio. In the second condition, R_{Ei} and R_{mini} can not be satisfied, or R_{mini} and R_{Ei} equals to R_{maxi}. So, if the packet of ith user is scheduled, it should only be scheduled to the RA with R_{maxi}. Then in this situation, $RA_{ij}(R_{ij})$ is 1 when $R_{ij} = R_{maxi}$, while, $RA_{ij}(R_{ij})$ is 0 when, $R_{ij}<R_{maxi}$. In the third condition, R_{Ei} can't be obtained, therefore, for QoS guarantee, the packet should be scheduled to the RA which can offer the higher bit rate than R_{mini}. The relation between $RA_{ij}(R_{ij})$ and R_{ij} is shown in Fig. 2b.

Considering features above, the scheduling utility function is defined as follow:

$$U_{ij}(t) = RA_{ij}(R_{ij}(t)) \cdot D_i(d_i(t)) \tag{9}$$

For satisfying QoS requirement while avoiding wasting resource, the scheduler should follow the rule to perform multi-radio packet scheduling which maximizes the scheduling utility function.

Multi-radio packet scheduling model: With assumption that every user only generates one real-time traffic and the packet in each user queue is scheduled based on FIFO rule, packet scheduling model in any transmission time interval (TTI) can be modeled as:

$$\max(\sum_{i=1}^{N}\sum_{j=1}^{M} U_{ij}(t) \cdot V_{ij}(t)) \tag{10}$$

$$\max(\sum_{i=1}^{N}\sum_{j=1}^{M} \frac{R_{ij}(t)}{R_i(t)} \cdot V_{ij}(t)) \tag{11}$$

$$\text{s.t.} \sum_{j=1}^{M} V_{ij}(t) = 1 \tag{12}$$

where, Eq. 10 is used to satisfy QoS requirement and improve spectrum efficiency. Equation 11 ensures fairness to all users. Equation 12 implies that one RA only can be allocated to one user in any TTI. N and M are numbers of user and available RA respectively. Obviously the solution of the scheduling model is a NP problem, which can be solved through some optimal algorithms, such as genetic algorithm (Huang *et al*., 2010) and neutral network (Ercsey-Ravasz *et al*. 2008). Another factor for algorithm design, execution time, should be considered. The execution time must be smaller than scheduling cycle, which is TTI in this study. So, a optimization tool is needed to fast and effectively find a optimal solution for the scheduling model. Fortunately HNN has some advantages which can help us to solve this problem. It is convenient for hardware realization and it then implemented by hardware circuit can acquire the optimal solution in microsecond, which is shown in Fig. 3. Considering these factors, a packet scheduling algorithm based on HNN is proposed in this study.

QU Algorithm based on HNN

Hopfield neural network: HNN is a interconnection neural network model and in HNN, the concept of energy function like Lyapunov function is introduced which corresponds the topological structure with problem to be solved and turns the problem to the evolution of neutral dynamics system. The evolution process is a nonlinear dynamic system and is described as a group of non-linear difference equations (discrete type) or differential equations (continuous type). System stability can be analyzed using so-called energy function whose energy, in case of meeting the given condition, decreases gradually and finally reaches a stable equilibrium point. If the point is considered as minimal point of energy function and energy function is employed to represent objective functions of a certain optimization problem. In some sense, evolution process coming from initial state to the stable point just is the process of solving the optimization problem. In fact, finding optimization solution don't need calculation but be implemented by constructing feedback neural networks and designing its connection weights and inputs.

QU algorithm based on HNN: In this study, continuous HNN is used whose structure is shown in Fig 3. It is comprised of a set of interconnected neurons. Neurons dynamically change their outputs until an equilibrium point is achieved. Hopfield proves that energy function E represents the dynamic change of the outputs and the equilibrium point can be obtained through finding local minimum value of E. The dynamics of the HNN can be expressed as Almajano and Perez-Romero (2002):

$$\frac{dU_{ij}}{dt} = -\frac{U_{ij}}{\tau} - \frac{\partial E}{\partial V_{ij}} \tag{13}$$

where, U_{ij} and V_{ij} are the input and output of the neuron (i, j) respectively. τ is the time constant. Sigmoid function is used as activation function of neuron which is expressed as:

$$V_{ij} = f(U_{ij}) = \frac{1}{1+e^{-\alpha_{ij}U_{ij}}} \tag{14}$$

where, $\alpha_{ij}>0$ is the shape parameter of the neurons, $U_{ij}\in[-8, +8]$ and $V_{ij}\in[0, 1]$. In order to solve above problem,

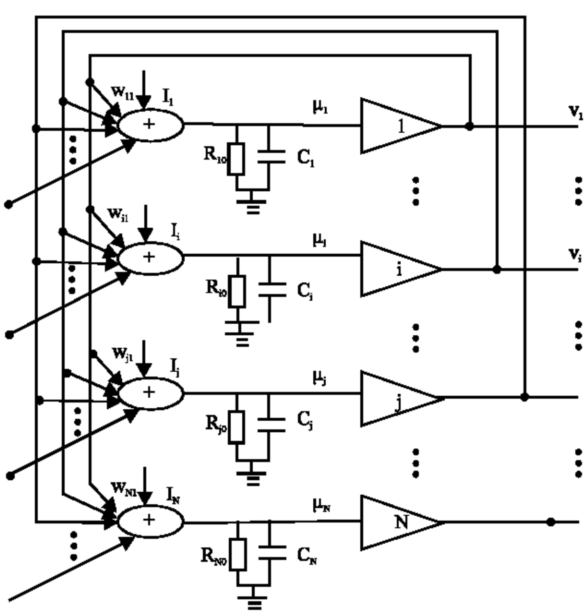

Fig. 3: Hardware implementation of continuous HNN

a 2-D HNN with N×M neurons is employed. Its energy function E is defined as:

$$\begin{aligned} E = &-\mu_1 \sum_{i=1}^{N}\sum_{j=1}^{M} U_{ij}(t)\cdot V_{ij}(t) - \mu_2 \sum_{i=1}^{N}\sum_{j=1}^{M} \frac{R_{ij}(t)}{R_i(t)}\cdot V_{ij}(t) \\ &+ \frac{\mu_3}{2}\sum_{i=1}^{N}\sum_{j=1}^{M} V_{ij}(t)(1-V_{ij}(t)) + \frac{\mu_4}{2}\sum_{i=1}^{N}(1-\sum_{j=1}^{M} V_{ij}(t))^2 \end{aligned} \tag{15}$$

where, the third term of Eq. 14 is used to make neurons rapidly converge to correct and stable states, i.e., 1 or 0. $V_{ij} = 1$ only when jth RA is allocated to ith user; otherwise, $V_{ij} = 0$. The fourth term ensures the allocation of only RA per user in any TTI. A numerical iterative solution for Eq. 13 is implemented according to the Euler rule as:

$$U_{ij}(t+\Delta t) = U_{ij}(t) + \Delta t\left\{-U_{ij}(t) - \frac{\partial E}{\partial V_{ij}}\right\} \tag{16}$$

where, Δt is the time interval over which the output of neurons are updated. The gradient of energy function can be calculated as:

$$\frac{\partial E}{\partial V_{ij}} = -\mu_1 U_{ij}(t) - \mu_2\frac{R_{ij}(t)}{R_i(t)} + \frac{\mu_3}{2}(1-2V_{ij}(t)) - \mu_4(1-\sum_{s=1}^{M} V_{is}(t)) \tag{17}$$

PERFORMANCE EVALUATION

Simulation parameters: It is considered that downlink transmission of data to N mobile user and the availability of M RAs belong to two different RATs. The simulated network consists of seven RAT1 cells (3km radius) and seven RAT2 cells (1.5 km radius) in a hierarchical cell structure, as demonstrated in Fig. 4. All Ras adopt time-division multiple access (TDMA) with a regular TTI of 2 msec. In simulation, fading channels between RAs are different. Path loss and shadowing adopts suburb model. Multi-path is implemented using the modified Jakes model. On the initial state all users are uniformly

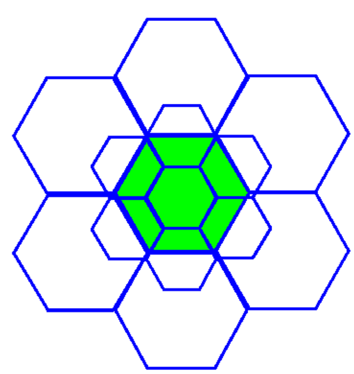

Fig. 4: Hierarchical cell structure

Table 1: Mcs selection criteria

SINB (dB)	MCS	Spectral efficiency
$-\infty<\gamma(t)\leq 1.69$	QPSK 1/3 rate	2/3 bits/sec/Hz
$1.69<\gamma(t)\leq 4.82$	QPSK 1/2 rate	1 bits/sec/Hz
$4.82<\gamma(t)\leq 7.21$	16-QAM 1/3 rate	4/3 bits/sec/Hz
$7.21<\gamma(t)\leq 11.8$	16-QAM 1/2 rate	2 bits/sec/Hz
$11.8<\gamma(t)\leq\infty$	64-QAM 1/2 rate	3 bits/sec/Hz

distributed in the green area and wrap-around technology is used to avoid border effects. The mobile speed is 3 km h^{-1}.

The physical layers of all RAs support adaptive single-carrier Modulation and Convolutional Coding (MCS). The spectrum efficiency in the MCS selection criteria is presented in Table 1 (Karimi *et al*., 2006).

Traffic model: VoIP with average rate of 64 Kbps is chosen as real-time traffic which is modeled by the interrupt deterministic process. The maximum delay and packet loss rate of VoIP are 60 msec and 5%. In order to evaluate performance of the MRPSH algorithm for real-time traffic, QU is simulated and compared with PLR and M-LWDF algorithms in terms of spectrum efficiency, packet loss ratio and average packet delay.

Performance evaluation: Simulation results are plotted in Fig. 5-7. Under low load condition, the performances of QU, PLR and M-LWDF algorithms are comparable in terms of spectrum efficiency, packet loss ratio and average delay. However, with the increase of user number, the performances of these algorithms start to differ from each other. Although, spectrum efficiency of these three algorithms are improved with increase of user number, QU algorithm has higher spectrum efficiency than PLR and M-LWDF algorithms when user number is over 62. Especially when user number reaches 68, compared other two algorithms, QU algorithm increases by 5% in spectrum efficiency. The reasons for this phenomenon is that when other conditions are equal, such as the actual delay and fairness, these two algorithms are inclined to schedule the user packet to the RA which can offer the highest bit rate, resulting in improving spectrum efficiency to some extent. Besides, avoiding wasting resource is also taken into consideration in QU algorithm, as shown in Eq. 5-7. Owing to this mechanism, QU algorithm can support more users than PLR and M-LWDF provided that packet loss ratio is satisfied. In another word, under high load, QU algorithm has lowest packet loss ratio among these three algorithms and then improve the system good throughput in a given spectrum bandwidth, i.e., spectrum efficiency. The above conclusion can also be drawn from Fig. 6. When user number is below 66, the packet loss ratio of QU algorithm is almost zero. For different number of users, the packet loss ratio of QU algorithm is always

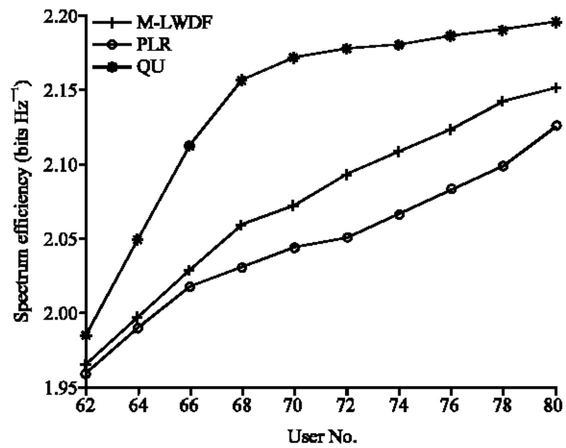

Fig. 5: Spectrum efficiency vs. users number

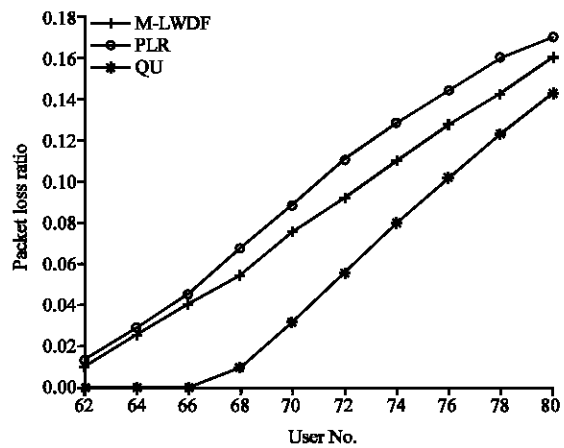

Fig. 6: Packet loss ratio vs. users number

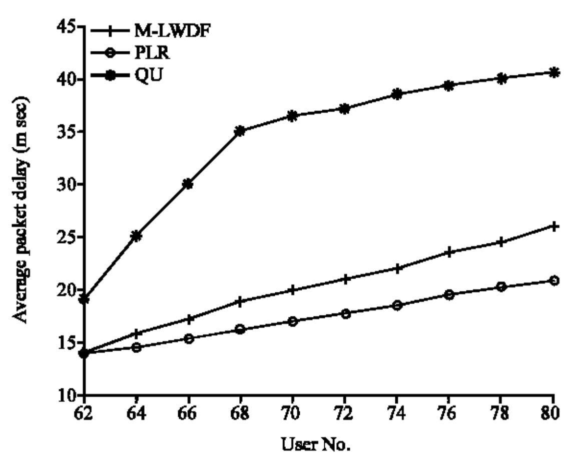

Fig. 7: Average packet delay vs. users number

lower than other algorithms. From Fig. 7, it is clearly demonstrated that QU algorithm has the larger average packet delay. The reason for the phenomenon is that QU algorithm avoids allocating excessive resources to the user whose QoS has already been satisfied. Though QU algorithm has larger average delay than other algorithms, it does not exceed the maximum allowable delay of real-time traffic.

CONCLUSION

In this study, GLL is introduced as a solution for integration of heterogeneous wireless access technologies and then in order to quickly and effectively schedule real-time traffic on the GLL, a novel multi-radio packet scheduling algorithm, QU, is proposed using HNN. QU algorithm adequately takes full advantage of multiuser diversity and multi-access diversity and improve spectrum efficiency under the premise of ensuring user' QoS. Compared with M-LWDF and PLR algorithms, under high load, QU algorithm has better performance in terms of packet loss ratio and spectrum efficiency, while maintains allowable average packet delay. It is worthwhile to note that HNN is suitable for hardware implementation, so the proposed algorithm is easily applied in practical system

ACKNOWLEDGMENT

This study is supported by the Major State Basic Research Development Program of China (China 973 program under Grant 2007CB310601) and Important National Science and Technology Specific Projects of China (2009ZX03004-001).

REFERENCES

Almajano, L. and J. Perez-Romero, 2002. Packet scheduling algorithm for interactive and streaming service under QoS guarantee in a CDMA system. Vehicular Technol. Conf., 3: 1657-1661.

Andrews, M., K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting and R. Vijayakumar, 2001. Providing quality of service over a shared wireless link. IEEE Commun. Mag., 39: 150-154.

Courcoubetis, C., G. Fouskas and R. Weber, 1994. On the performance of an effective bandwidth formula. Proc. Int. Teletraffic Cong., 5: 6-10.

Dimou, K., R. Aguero, M. Bortnik, R. Karimi and G.P. Koudouridis *et al*., 2005. Generic link layer: A solution for multi-radio transmission diversity in communication networks beyond 3G. Vehicular Technol. Conf., 3: 1672-1676.

Ercsey-Ravasz, M., T. Roska and Z. Neda, 2008. Cellular neural networks for NP-hard optimization. Cell. Neural Networks Appl., 1: 52-56.

Eshanta, O.M., M. Ismail, K. Jumari and P. Yahaya, 2009. VHO strategy for QoS-provisioning in the WiMAX/WLAN interworking system. Asian J. Applied Sci., 2: 511-520.

Huang, C.C., R.G. Chung, R.C. Chen, T.S. Chen, T.N. Le, C.J. Hsu and Y.C. Tsai, 2010. Finding an optimal combination of key training items using genetic algorithms and support vector machines. Inform. Technol. J., 9: 652-658.

IEEE, 2006. IEEE standard for local and metropolitan area networks-part16: Air interface for fixed and mobile broadband wireless access systems. IEEE Std. 802.16e-2005 and IEEE Std. 802.16-2004, February 2006, IEEE Xplore London, pp: 1-822.

Jalali, A., R. Padovani and R. Pankai, 2000. Data throughput of CDMA HDR a high efficiency-high data rate personal communication wireless system. Vehicular Technol. Conf. Proc., 1: 1854-1858.

Karimi, H.R., K. Dimou., G.P. Koudouridis and P. Karlsson, 2006. Switched multi-radio transmission diversity for non-collocated radio accesses. Vehicular Technol. Conf., 1: 167-171.

Liu, G., J. Zhang, B. Zhou and W. Wang, 2007. Scheduling performance of real time service in multiuser OFDM system. Proceedings of the International Conference on Wireless Communications, Networking and Mobile Computing, Sept. 21-25, Shanghai, pp: 504-507.

LTE, 2006. Mobile broadband: The global evolution of UTMS/HSPA-3GPP release 7 and beyond. 3G Americas Whitepaper, July 2006. http://whitepapers.techrepublic.com.com/abstract.aspx?docid=308653.

Sach, J., H. Wienmnn and P. Magnusson, P. Wallentin and J. Lundsjo, 2004. A generic link layer in a beyond 3G multi-radio access architecture. Commun. Circuits Syst., 1: 447-451.

Sang, A., X. Wang and M. Madihian, 2007. Real-time QoS in enhanced 3G cellular packet systems of a shared downlink channel. Wireless Commun. Mag., 6: 1803-1812.