Power-Efficient Radio Resource Allocation for Low-Medium-Altitude Aerial Platform Based TD-LTE Networks

Liqiang Zhao[1, 2], Chi Zhang[1], Hailin Zhang[1] and Xiaohui Li[1]

1. State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an, Shaanxi 710071, China
2. National Mobile Communications Research Laboratory, Southeast University, Nanjing, Jiangsu 210096, China

E-mail：lqzhao@mail.xidian.edu.cn

Lajos Hanzo
School of Electronics and Computer Science
University of Southampton
Southampton, UK
E-mail：lh@ecs.soton.ac.uk

Abstract—**In order to provide an increased capacity, throughput and QoS guarantee for terrestrial users in emergency scenarios, a low-medium-altitude aerial platform based time-division-duplex long term evolution (TD-LTE) system referred to as Aerial LTE, is presented in this paper. Additionally a power-efficient radio resource allocation mechanism is proposed for both the Aerial LTE downlink and uplink, which is modeled as a cooperative game. Our simulation results demonstrate that the proposed algorithm imposes an attractive tradeoff between the achievable throughput and the power consumption while ensuring fairness among users.**

Keywords-low medium-altitude aerial platform; TD-LTE; radio resource allocation; power efficiency; game theory

I. INTRODUCTION

On 12 May 2008, Wenchuan in China was hit by a destructive earthquake. All the terrestrial telecommunication systems were damaged. Hence Wenchuan lost its links with the outside world. A similar scenario occurred after the recent tsunami near Sendai, Japan. Since then low-medium-altitude aerial platforms (LMAPs) as emergency communication systems, have attracted significant interest from government, academia and industry [1]. Captive balloons are stationary at low-medium-altitudes ranging from about 2 km to 20 km and cover a wide area. This makes them an attractive option for carrying telecommunication equipment. LMAPs may carry equipment obeying diverse wireless standards, including 3G/B3G, LTE, WiMAX or combinations of them.

The time-division-duplex long term evolution (TD-LTE) system is considered as one of the candidate technologies for the next generation mobile communications systems [2]. Hence an aerial platform-based TD-LTE system, Aerial LTE, is presented in this paper for providing emergency services in disaster areas.

One of the key technologies designed for managing a high tele-traffic during disasters is radio resource management (RRM). Diverse RRM algorithms have been proposed for LTE to achieve different requirements. For example, the authors of [3] and [4] proposed algorithms for maximizing the system throughput, while ensuring fairness in both the LTE downlink (DL) and uplink (UL). A joint resource allocation algorithm simultaneously considering the time-frequency-power-domain based on the Nash bargaining solution (NBS) was implemented in a multi-cell WiMAX-based LMAP system in our previous work [1].

However, providing seamless power supply for LMAPs is a challenging problem, especially in disaster areas. Previous RRM algorithms have not considered the issues of power efficiency. The authors of [5-8] have adaptively allocated the power to subcarriers, but they have not considered fairness in the context of diverse applications.

In this study we use game theory for power-efficient RRM in the context of the Aerial LTE uplink and downlink.

The rest of this paper is organized as follows. In Section II we develop the system model of both the Aerial LTE UL and DL. In Section III and IV, a power-efficient radio resource allocation algorithm is detailed. In Section V, simulations are carried out to evaluate the performance of the proposed algorithm. Our conclusions are offered in Section VI.

II. SYSTEM MODEL

A typical Aerial LTE scenario includes the aerial NodeBs (aNBs) and the user equipment (UEs) on the ground. Each NodeB supports a traffic cell and all the UEs are randomly distributed in these areas. According to the LTE standard [2], our system relies on orthogonal frequency diversion multiplexing (OFDM) in the DL and single carrier frequency division multiple access (SC-FDMA) in the UL. The scheduler of an aNB is responsible for allocating radio resources to both the UL shared channel (UL-SCH) and to the DL shared channel (DL-SCH), in order to maximize the power efficiency, while ensuring fairness among the UEs as well as maintaining the required QoS for different traffic requirements. The radio resources defined in the LTE standard include the resource blocks (RB), the specific modulation and coding schemes

(MCS), the power allocation schemes and the antenna options. In other words, we have five resource categories which are the time, frequency, code, power, and spatial domains respectively. A RB, which is composed of 12 consecutive sub-carriers occupying 180 kHz in the frequency domain (FD) and one time slot of 0.5 ms duration in the time domain (TD), is the minimum frequency-time resource unit. A time slot (TS) hosts 6 or 7 OFDM symbols in the DL or SC-FDMA symbols in the UL. This allows us to formulate the RB allocation in a matrix-like structure. However, in line with other standards, the LTE standards do not explicitly specify the RRM schemes because different service-providers and operators have different spectrum allocations. Furthermore, this open structure facilities the creation of new innovative algorithms. For simplicity, we only consider RB and power allocation in this paper.

The proposed power-efficient RRM can be modeled as the following optimization problem based on the cooperative game theory.

$$\max_{\mathbf{X},\mathbf{P}} \sum_{n=1}^{N} U_n(\gamma_n) = \max_{\mathbf{X},\mathbf{P}} \sum_{n=1}^{N} \frac{\mathrm{r}_n(\gamma_n)}{\mathrm{P}_n}, \tag{1}$$

subject to:

$$\begin{gathered} P_{n,k,t} \geq 0 \quad \forall n,k,t \\ \sum_{n=1}^{N} x_{n,k,t} = 1 \quad x_{n,k,t} = \{0,1\} \quad \forall k,t, \\ \sum_{n}\sum_{k}\sum_{t} P_{n,k,t} \leq P_{\max,aNB} \end{gathered} \tag{2}$$

where **X** and **P** denote the RB allocation (RBA) and power allocation (PA) matrix, respectively; N is the number of UEs in a given cell; γ_n is the signal to interference plus noise ratio (SINR) of the nth UE (UE_n). If $RB_{k,t}$ at the k-th row and t-th column of the matrix **X** is assigned to UE_n, then we have $x_{n,k,t}=1$ and its assigned power is $P_{n,k,t}$; otherwise, we have $x_{n,k,t}=0$. Since a RB in each aerial NodeB can be assigned to one and only one UE, we have $\sum_{n=1}^{N} x_{n,k,t} = 1$. Furthermore, the sum of the assigned transmission power is less than the maximum transmission power $P_{max,aNB}$ of aNBs.

The utility of the n-th UE is defined as $U_n(\gamma_n) = r_n(\gamma_n) / P_n$, where r_n is its data rate and P_n is the power assigned to a specific aNB transmission to UE_n. In other words, the utility is defined as the system's power efficiency. Naturally, efficient joint time-frequency-power resource allocation is only achievable, if accurate channel state information (CSI) is available. For simplicity, we assume that each aNB can get perfect CSI for all of its UEs.

III. Power-Efficient Radio Resource Allocation for the Downlink

Since all UEs compete with each other for the time-frequency-power resources, cooperative game theory is adopted for optimizing RRM for the DL. Its basic approach is that once all the minimal requirements were satisfied for all UEs, the rest of the resources are allocated to UEs for maximizing the aNB's power efficiency. This approach was adopted to ensure fairness among the UEs. Accordingly, the RRM approach of (1) may be reformulated as follows:

$$\max_{\mathbf{X},\mathbf{P}} \sum_{n=1}^{N} \left[U_n(\gamma_n) - U_{n,\min}\right] = \max_{\mathbf{X},\mathbf{P}} \sum_{n=1}^{N} \frac{r_n(\gamma_n) - r_{n,\min}}{P_n - P_{n,\min}}, \tag{3}$$

subject to:

$$\begin{gathered} P_{n,k,t} \geq 0, \forall n,k,t \\ \sum_{n=1}^{N} x_{n,k,t} = 1 \quad x_{n,k,t} = \{0,1\}, \forall k,t. \\ \sum_{n}\sum_{k}\sum_{t} P_{n,k,t} \leq P_{\max,aNB} \end{gathered} \tag{4}$$

In order to reduce the complexity imposed, we partition the optimization problem into two sub-problems having a lower complexity, namely into separate time-frequency resource allocation and power allocation.

A. Time-frequency resource allocation

It is assumed that the transmit power will be equally distributed among RBs, i.e., we have

$$P_{n,k,t} = \begin{cases} P_{\max,aNB} / (K \cdot T) & x_{n,k,t} = 1 \\ 0 & x_{n,k,t} = 0 \end{cases}. \tag{5}$$

Given the power allocation matrix **P**, the optimization problem (3) may be simplified to

$$\max_{\mathbf{X}} \sum_{n=1}^{N} \left[U_n(\gamma_n) - U_{n,\min}\right] = \max_{\mathbf{X}} \sum_{n=1}^{N} \frac{r_n(\gamma_n) - r_{n,\min}}{P_n - P_{n,\min}}, \tag{6}$$

subject to:

$$\sum_{n=1}^{N} x_{n,k,t} = 1 \quad x_{n,k,t} = \{0,1\} \quad \forall k,t, \tag{7}$$

where $U_{n,min}$ is the minimum utility requirement of UE_n, $r_{n,min}$ is its minimum required data rate, while $P_{n,min}$ is the corresponding minimum required transmission power.

By using the classic Lagrange multiplier method [1], we arrive at

$$\begin{cases} U_n'(\gamma_n) \times \dfrac{r_n}{P_n} = \lambda & if\ x_{n,k,t} = 1 \\ U_n'(\gamma_n) \times \dfrac{r_n}{P_n} \leq \lambda & if\ x_{n,k,t} = 0 \end{cases}. \tag{8}$$

Thus the closed form solution of the RB assignment can be obtained in the form of

$$n = \arg\max_{n} \left[U_n'(\gamma_n) \times \frac{r_n}{P_n} \right], \tag{9}$$

where $RB_{k,t}$ is allocated to the nth UE for maximizing $U_n^{'}(\gamma_n)\times\frac{r_n}{P_n}$.

B. Power allocation

So far we have addressed the RB allocation problem under the assumption that the same power is assigned to all RBs. Therefore, based on the generated RBA results, we simply have to re-allocate the transmission power among all the RBs. The optimization problem (3) can hence be re-formulated as:

$$\begin{aligned}&\max_{\mathbf{P}}\sum_{n=1}^{N}\left[U_n(\gamma_n)-U_{n,\min}\right]\\&=\max_{\mathbf{P}}\sum_{n=1}^{N}\frac{1}{P_n-P_{n,\min}}\left(\sum_{k=1}^{K}x_{n,k,t}r_{n,k}-r_{n,\min}\right)\end{aligned}, \tag{10}$$

subject to:

$$\begin{aligned}&P_n\geq 0\quad\forall n\\&\sum_{n=1}^{N}P_n\leq P_{\max,aNB}\end{aligned}. \tag{11}$$

Similarly, after using the Lagrange multiplier method, we take the derivatives of $U_n(\gamma_n)-U_{n,\min}$ with respect to P_n. Then, according to the Karush-Kuhn-Tucker (KKT) condition [11], we arrive at

$$\begin{cases}U_n^{'}(\gamma_n)\times\gamma_n^{'}(P_n)-\lambda=0\\\sum_{n=1}^{N}P_n\leq P_{\max,aNB}\end{cases}. \tag{12}$$

By solving the above equations, we finally arrive at the optimal power allocation matrix **P**.

C. Joint time-frequency-power resource allocation

To summarize, the proposed algorithm may be decomposed into three steps. Firstly, we assume that the transmission power is equally distributed among all the RBs. Based on the estimated SINR, the optimal RB assignment matrix **X** may be obtained according to Equation (9). Secondly, based on the RB allocation results, the power allocation matrix **P** can be generated according to Equation (12). Finally, we substitute the power allocation results obtained during the second step into the first step and update the RB assignment. This iteration continues until the result converges [1].

IV. Power-Efficient Radio Resource Allocation for the Uplink

Compared to the UL, typically, more data are transmitted in the DL. However, the UL may occupy most of the radio resources in emergency communications. A short message may be transmitted in the DL to inform rescuers about their expected actions. On the other hand, large amounts of information such as statistical data, images and video may be transmitted in the UL. Hence, a power-efficient RRM algorithm may be formulated for the UL, which is modeled as:

$$\max_{\mathbf{P}}U_n(\gamma_n)=\max_{\mathbf{P}}\frac{r_n}{P_n}, \tag{13}$$

subject to: $$0\leq P_n\leq P_{\max,UE}\quad\forall n, \tag{14}$$

where the maximum transmission power of UEs is $P_{max,UE}$.

It has been shown that the above utility function $U_n(\gamma_n)$ is quasi-concave around the value of P_n [10]. Hence, after taking the derivatives of $U_n(\gamma_n)$ with respect to P_n, and setting the result to 0, we arrive at the optimal solution as:

$$P_n^{\Delta}=\frac{f(\gamma_n)}{f^{'}(\gamma_n)\cdot\gamma_n^{'}}, \tag{15}$$

where $P^{\Delta}=(P_1^{\Delta},\ldots,P_N^{\Delta})$ becomes the optimal solution **P**, if it satisfies the constraint (14). Otherwise, since the utility function $U_n(\gamma_n)$ of UE_n is an increasing function, the upper bound of the transmission power will be the maximum value. Hence the optimal power P_n^* is expressed as

$$P_n^*=\begin{cases}P_n^{\Delta} & \text{if } 0\leq P_n^{\Delta}\leq P_{\max,UE}\\P_{\max,UE} & \text{otherwise}\end{cases}. \tag{16}$$

V. Performance Evaluation

We consider a rectangular area of 50km×50km on the ground, which is serviced by seven aNBs. The aNBs are assumed to be installed on captive balloons of 2km in height, and the UEs are randomly distributed in these traffic cells. The free path loss model is adopted for the air-ground radio link. The main system parameters are given in Table I [2]

TABLE I. Simulation Parameters

Carrier frequency	2.6 GHz
Bandwidth	5, 10, 15, 20 MHz
Maximum transmit power of aNBs	43 dBm
Maximum transmit power of UEs	23 dBm
Modulation	16QAM
Coding	Turbo 2/3
DL:UL ratio	1:1

Four different types of service requirements are considered, which are VoIP, web-browsing, file-download and video, which are supported at data rates of 64kbps, 128kbps, 384kbps and 1024kbps, respectively. Each UE opts for one service evenly. The proposed algorithm is simulated using MATLAB and in order to evaluate its attainable performance, the well-established max-rate, max-min algorithm and the joint time-frequency-power allocation strategy algorithm, which was referred as JEEP in [1], are employed in the same scenarios.

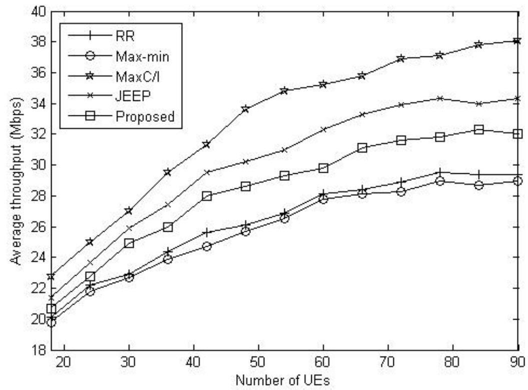

Figure 1. System throughput vs. the number of UEs

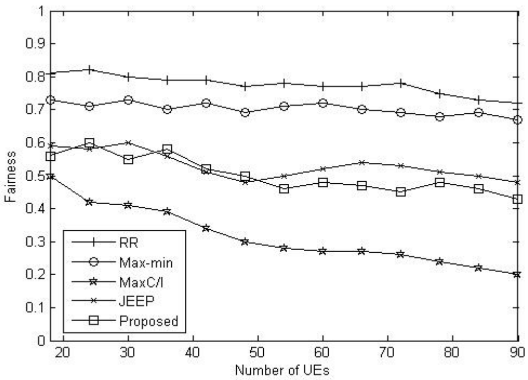

Figure 2. Fairness vs. the number of UEs

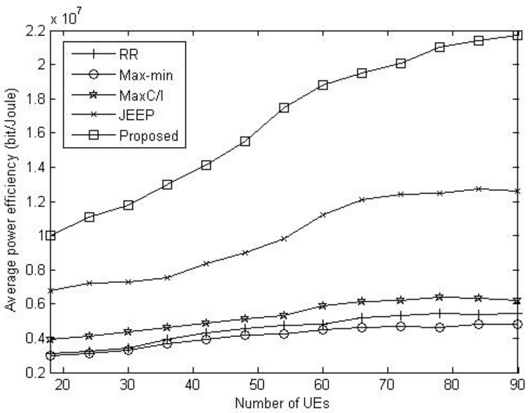

Figure 3. Power efficiency vs. the number of UEs

Fig. 1, 2 and 3 show the system's throughput, fairness, and power efficiency for different number of UEs respectively, where the channel bandwidth is fixed at 20MHz. In the Max-C/I algorithm [13], in order to achieve the maximum data rate, aNBs will allocate each RB to the specific UEs having the best channel conditions. Hence, its throughput constitutes the upper bound of all the algorithms considered, as shown in Fig. 1. However, its lower fairness and reduced power efficiency is an obvious impediment, as shown in Fig. 2 and Fig. 3. Fairness is quantified in terms of the fairness index β [12].

The RR algorithm takes turns to allocate RBs to each UEs. Hence, its fairness constitutes the upper bound of all the algorithms, as shown in Fig. 2. The max-min algorithm allocates more subchannels to UEs suffering from degraded channel conditions to ensure fairness, but as a result, its system throughput becomes the lowest. However, it achieves a good fairness. In the JEEP algorithm [1], the resources are proportionally allocated according to each UE's channel conditions after satisfying the minimum requirement. Thus, the JEEP algorithm strikes a tradeoff between throughput and fairness, but its power efficiency is significantly lower than that of the proposed algorithm, which achieves the highest power efficiency by sacrificing its throughput. Thus its throughput becomes lower than that of JEEP.

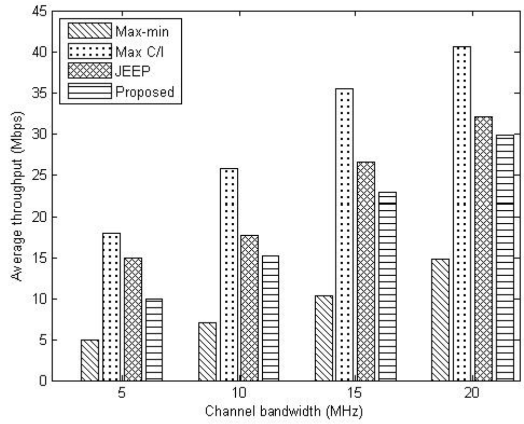

Figure 4. System throughput vs. channel bandwidth

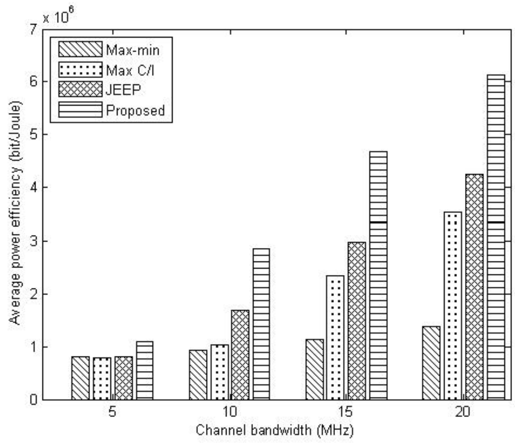

Figure 5. Power efficiency vs. channel bandwidth

Fig. 4 and 5 show the system's throughput and power efficiency for different channel bandwidths, respectively. Since the available resources become more abundant with the increase of bandwidth, the performance of each algorithm is improved. The max-rate algorithm attains the maximum throughput, while the RR algorithm obtains the maximum fairness, and the proposed algorithm achieves the maximum power efficiency.

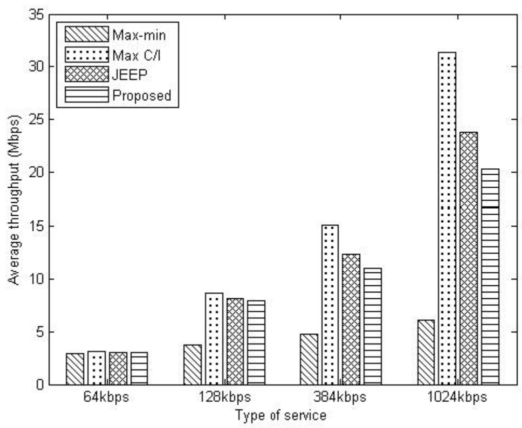

Figure 6. System throughput vs. type of service

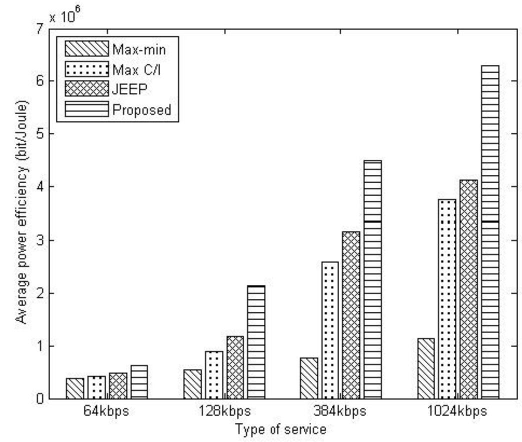

Figure 7. Power efficiency vs. type of service

Fig. 6 and 7 show both the achievable throughput and power efficiency of the four algorithms for different types of services. Since the system is not saturated under light tele-traffic requirements (e.g., 64kbps), the throughput of the max-C/I, the JEEP and the proposed algorithm is almost the same at about 3Mbps. When the required rate of the service increases, say to 1024kbps, the system's resources no longer can support all the requirements. The four algorithms attain different throughputs. The throughput of the max-C/I technique is the largest, up to 32Mbps; that of the proposed algorithm is more than 20Mbps; that of the max-min technique is the lowest, about 5Mbps. On the other hand, the power efficiency of the proposed algorithm is always higher than that of the other algorithms under the different traffic requirements considered.

VI. CONCLUSIONS

In this paper, an LMAP-based TD-LTE system was proposed for supporting emergency services in disaster areas. Game theory was used to develop a power-efficient RRM algorithm for both the uplink and downlink. Since the provision of ceaseless power supply is a challenge in disaster areas, the proposed algorithm adopted the power efficiency as its salient utility function and increased the achievable power efficiency without any substantial reduction in the QoS. Our simulation results demonstrated that the attainable power efficiency of the proposed algorithm is significantly higher than that of all the other RRM algorithms. As a price, its throughput is lower than that of the max-rate and JEEP techniques.

ACKNOWLEDGMENT

This work is supported by the 111 Project (B08038), EU FP7 MONICA Project (295222), National High Technology Research and Develop Program of China (863 Program) (No. 2012AA120604), the Open Research Fund of National Mobile Communications Research Laboratory, Southeast University (2012D01), Program for New Century Excellent Talents in University (NCET-08-0810), and National Natural Science Foundation of China (No. 60772137).

REFERENCES

[1] L. Zhao, Li Cong, F. Liu, "Joint time-frequency-power resource allocation for Low-medium altitude platforms based WiMAX Networks," IET Communications, May 2011, pp.967–972.

[2] 3GPP TS 36.211 V8.6.0, Physical Channels and Modulation (Release 8), Mar. 2009, available at: www.3gpp.org.

[3] L. Anchora, L.Canzian, L.Badia, M. Zorzi, "A characterization of resource allocation in LTE systems aimed at game theoretical approaches," IEEE International Workshop on CAMAD, 2010, pp.47–52.

[4] E. Yaacoub and Z. Dawy, "A game theoretical formulation for proportional fairness in LTE uplink scheduling," IEEE Wireless Commun. Netw. Conf., 2009, pp.1–5.

[5] G. Song, Y. Li, "Adaptive resource allocation based on utility optimization in OFDM," IEEE GLOBECOM, Volume 2, Dec.2003, pp.586– 590.

[6] W. Kuo, W. Liao, "Utility-based optimal resource allocation in wireless networks," IEEE GLOBECOM, Volume 6, Dec.2005, pp.5.

[7] C. Curescu, S. Nadjm-Tehrani, "Time-aware utility-based resource allocation in wireless networks," IEEE Transactions on Parallel and Distributed Systems, July 2005, pp.624–636.

[8] G. Song, Y. Li, "Utility-based resource allocation and scheduling in OFDM-based wireless broadband networks" IEEE Communications Magazine, Dec. 2005, pp.127–134.

[9] C.U. Saraydar, N.B. Mandayam, D.J. Goodman, "Efficient power control via pricing in wireless data networks," IEEE Trans. Commun., Feb.2002, pp. 291–303.

[10] V.Srivastava, J.Need, A. B. Mackenzie, "Using game theory to analyze wireless ad hoc networks," Commun. Surveys & Tutorials, 2005, pp.46–53.

[11] S. Boyd, L. Vandenberghe, "Convex Optimization", Cambridge University Press, 2004, pp.1074–1079.

[12] J. H. Huang, L. C. Wang, C. J. Chang, "Power Fairness in a Scalable Ring-Based Wireless Mesh Network," IEEE Vehicular Technology Conference, Baltimore, MD, Sept. 2007, pp. 341-346.

[13] S. Periyalwar, B. Hashem, G. Senarath, K. Au, R. Matyas, "Future mobile broadband wireless networks: a radio resource management perspective," Wiley Journal of Wireless Communications and Mobile Computing, vol. 3, no. 7, Nov. 2003, pp. 803–816