WLAN / WMAN INTEGRATION ARCHITECTURE AND TRAFFIC CONTROL FOR VOICE TRANSMISSION

Boris Tsankov, Kiril Kassev, Radostin Pachamanov

Abstract: The popular technologies Wi-Fi and WiMAX for realization of WLAN and WMAN respectively are much different, but they could compliment each other providing competitive wireless access for voice traffic. The article develops the idea of WLAN/WMAN (Wi-Fi/WiMAX) integration. WiMAX is offering a backup for the traffic overflowing from Wi-Fi cells located into the WiMAX cell. Overflow process is improved by proposed rearrangement control algorithm applied to the Wi-Fi voice calls. There are also proposed analytical models for system throughput evaluation and verification of the effectiveness using WMAN as a backup for WLAN overflow traffic and the proposed call rearrangement algorithm as well.

Keywords: WLAN/WMAN integration, Wi-Fi, WiMAX, voice traffic.

ACM Classification Keywords: C.2.5. Local and Wide Area Network, C.4. Performance of Systems – Voice Traffic

Conference: The paper is selected from Sixth International Conference on Information Research and Applications – i.Tech 2008, Varna, Bulgaria, June-July 2008

Introduction

Two different air interface standards for wireless access to telecommunication core network became recently very popular. The first standard is for wireless LAN (WLAN), called Wi-Fi (Wireless Fidelity) by Wi-Fi Alliance [1] that certifies network devices to comply with the IEEE 802.11 standard (last version [2]). Today Wi-Fi is widely used and now almost all laptops and other handheld devices as well came with Wi-Fi build-in. The second standard is for wireless MAN (WMAN), called WiMAX (Worldwide Interoperability for Microwave Access) by the WiMAX Forum [3] that promotes conformance and interoperability of the IEEE 802.16 standard [4]. Both standards offer user mobility, and are used for voice traffic although, it is not in the same circumstances.

The differences between Wi-Fi and WiMAX are well known [5], but we are looking for an opportunity to complement each other and to integrate them into one wireless access system for voice traffic.

Wi-Fi is unbeatable to install fast, easy and cheap A*ccess Point* (AP). The cell radius is optimized around 100 m. The standard and its contention-based MAC can not guarantee the required Quality of Service (QoS) and especially the very important QoS parameter - voice latency. The standard does not allow for differentiated service level for each user. A possible solution of QoS guarantee is to substitute the widespread use of *Distributed Coordination Function* (DCF) with *Point Coordination Function* (PCF) although with some loss of simplicity.

WiMAX equipments are considerably more expensive and the range of covering is somewhat 5 to 50 km distance from the *Base Station* (BS). The 802.16 standard is with well developed centralized system of *Polling Services* of a *Request-Grant* MAC and specifically designed to support voice. The WiMAX system throughput (hundreds of voice connections) is much more than Wi-Fi throughput (hardly exceeding 10 -20 voice connections). The WiMAX call range and throughput can be increased introducing provided by the standard mesh mode (see [6] and the references therein).

There are proposals for integration of Wi-Fi with 3G cellular networks [7], [8]. Integration between WiMAX and space based telecommunication infrastructure is considered in [9]. Finally, there are some attempts to integrate

Wi-Fi and WiMAX [10], [11], [12]. In all these cases of heterogeneous networks the subscriber devices have to be compatible with different standards employed. One approach is to associate the existing separated systems in a device. Another, more advanced approach is proposed in [13] for Wi-Fi/WiMAX integration instead of a simple duplication of the radio systems.

In this article WLAN/WMAN (Wi-Fi and WiMAX) network architecture is considered and a particular mechanism for traffic control (rearrangement of calls) is proposed. Analytical methods proposed by authors for capacity analysis are applied. Numerical results are presented with an evaluation of the served traffic gain due to integration and due to proposed call rearrangements.

The terms WLAN – Wi-Fi and WMAN – WiMAX as well will be used in the article text interchangeable.

System Description

The proposed WLAN/WMAN integrated access network is depicted on Fig. 1. The Wi-Fi *hot spots* do not cover the entire WiMAX cell, but only the areas with expected high density of traffic sources. There is separate backhauling organized for BS and Aps to the edge router of the core network, but there are other possible arrangements as well. Special controls tasks are assigned to *Resource Manager* (RM on Fig. 1).To fulfill its traffic control functions the RM is connected to BS and Aps with signaling channels. RM might be incorporated with WiMAX BS. A subscriber located in the coverage of a Wi-Fi cell can be served by both – WLAN and WMAN, but always at first an attempt is made the arriving call to be served by the WLAN. A subscriber located in the coverage of WMAN only is served by WMAN. We will consider two possible algorithms of traffic control for subscriber located in the coverage of both systems:

- *Overflowing.* If there are enough resources in the WLAN cell, the arriving call is put into service by the WLAN. In case there are not enough resources in the WLAN cell, the arriving call is directed to the WMAN network. If there are not enough resources in WMAN either, the call is lost. Such algorithm of traffic control is proposed in [12] and in an author's previous work [14], where the cell corresponding to WMAN is called *umbrella-cell.* This algorithm we will call here *Simple Overflowing* (SO).
- *Overflowing with Rearrangement.* This algorithm is an extension of the previous one. If during the service in WMAN of an overflow call, in the WLAN cell of that call one resource became free (i.e. the service of one call in the WLAN considered has been completed), the overflow call is directed back (*rearranged*) to his WLAN to complete its service there. The algorithm is proposed by the authors in [14] and it is called here correspondingly O*verflowing with Rearrangement* (OR).

When we say "number of resources" of certain device, we have in mind the number of voice calls can be served through that device. This numbers are fixed by means of a Call Admission Control (CAC) mechanism acting in BS and each AP (Fig. 1).

System Throughput Evaluation

We are proposing analytical methods for system capacity analysis for both algorithms separately.

For SO we will apply the well known *equivalent random theory* [15], [16, p. 156] proposed by R. Wilkinson to solve the problem that the overflowing traffic is not Poisson traffic any more.

Suppose there are *k* WLANs; the traffic arriving at WLAN *i* is A_i ($i = 1,...,k$); WLAN *i* has n_i resources forming a full-availability group. The traffic overflowing from WLAN *i* is with mean value:

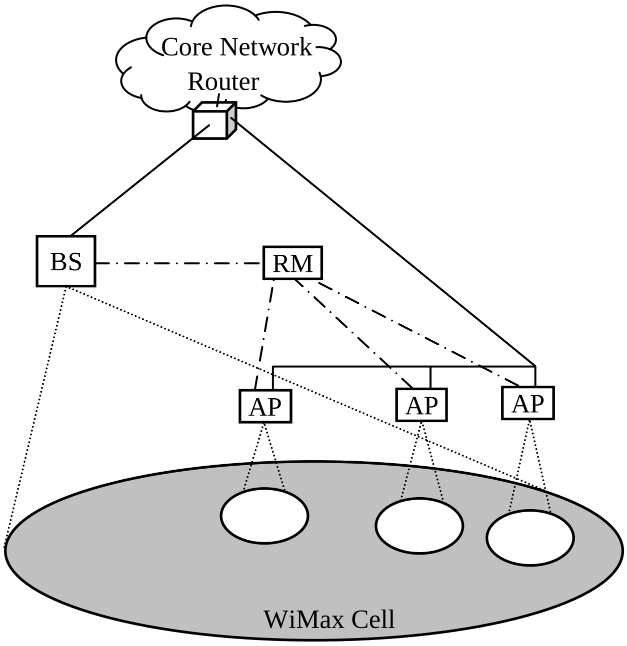

Fig. 1. WLAN/WMAN integration architecture

$$M_i = A_i E_B(n_i, A_i) \tag{1}$$

and variance

$$V_i = M_i \left[\frac{A_i}{n_i + 1 - A_i + M_i} + 1 - M_i \right] \tag{2}$$

Notation $E_B(n, A)$ corresponds to Erlang's B formula for traffic *A* arriving at *n* devices.

The traffic arriving at WMAN has the values

$$M = \sum_{i=1}^{k+1} M_i \qquad V = \sum_{i=1}^{k+1} V_i \tag{3}$$

The values indexed with $k+1$ correspond to "fresh" (Poisson) traffic $A_{i+1} = V_{i+1} = A_{WMAN}$, arriving directly to WMAN from the WiMAX subscriber station SS. The parameters n_e and A_e of the equivalent group are chosen in such a way that the traffic overflowing from it has the same *M* and *V* as the obtained by (3). The values of n_e and A_e are derived from the following equations

$$\left| \begin{array}{l} M = A_e E_1(n_e, A_e) \\ V = M \left[\dfrac{A_e}{n_e + 1 - A_e + M} + 1 - M \right] \end{array} \right. \tag{4}$$

Effective approximate solution of (4) is given by Y. Rapp [15]:

$$\begin{array}{l} A_e \approx V + 3z(z-1) \\ n_e \approx A_e \dfrac{M + z}{M + z - 1} - 1 - M \end{array} \tag{5}$$

where $z = V/M$.

Traffic loss probability is given by

$$B = E_B(n_e + n_{WMAN}, A_e) \tag{6}$$

n_{WMAN} is resource number in WMAN. Eq. (7) can be used to derive the necessary WMAN resources.

For OR although the call control algorithm is more sophisticated it is possible to derive a relatively simple analytical method for calculating the losses and the throughput afterwards. We will consider the system on Fig. 1 as a pool of

$$n = n_{WMAN} + \sum_{i=1}^{k} n_i$$

resources used by all $k+1$ traffic flows with the following restrictions: each WLAN traffic flow A_i can use only $n_i + n_{WMAN}$ resources; flow A_{WMAN} can use only n_{WMAN} resources. We propose to apply the multidimensional Erlang's-B formula [16], [17]:

$$p(j_1, j_2, ..., j_k, j_{WMAN}) = Q \frac{A_{WMAN}^{j_{WMAN}}}{j_{WMAN}!} \prod_{i=1}^{k} \frac{A_i^{j_i}}{j_i!}, \quad j_i = 0,...,n_i;\ j_{WMAN} = 0,...,n_{WMAN}$$
$$Q^{-1} = p(0,...,0) \tag{7}$$

Calculation of state probabilities (7) can be simplified using the convolution method, first time proposed by V. Iversen [16, p. 180]. The convolution algorithm used we will describe with following steps. Notations with index *k+1* stand for WMAN.

1) Calculate the state probabilities for each flow assuming there are not other flows in the system:

$$P_i = \{p_i(0), p_i(1), ..., p_i(n_i)\}, \quad i = 1,...,k+1 \tag{8}$$

It is important only the relative value of probabilities $p_i(x)$, therefore start with $q(0) = 1$ and calculate the values of $q_i(x)$ as ratio to $q(0)$. Normalize the relative state probabilities:

$$p_i(j) = \frac{q_i(j)}{Q_i}, \quad j = 0,1,...,n_i$$
$$Q_i = \sum_{j=0}^{n_i} q_i(j), \quad i = 1,...,k+1 \tag{9}$$

2) By consecutive convolutions calculate the aggregate state probabilities for the total system excluding *i*-th traffic flow:

$$Q_{(k+1)/i} = P_1 * P_2 * ... * P_{i-1} * P_{i+1} * ... * P_{k+1} \tag{10}$$

Calculations are done consecutively from left to right.

3) Calculation the traffic losses. First calculate the convolution:

$$Q_{k+1} = Q_{(k+1)/i} * P_i \tag{11}$$

The result from this convolution is:

$$Q_{k+1}(j) = \sum_{x=0}^{j} Q_{(k+1)/i}(j-x).p_i(x) = \sum_{x=0}^{j} p_x^i(j) \tag{12}$$

where in the term $p_x^i(j)$, *i* is traffic flow number, *j* is the total number of busy resources and *x* is number of busy resources of *i*-th flow.

Repeating both steps 2) and 3) for every traffic flow, the traffic losses for *i*-th flow are:

$$B_i = \sum_{j \in \Omega_i} p_x^i(j)/Q \quad (13)$$

where Ω_i the set of states for which the calls of *i*-th traffic flow are rejected.

Q is the normalization constant:

$$Q = \sum_{j=0}^{n} Q_{k+1}(j) \quad (14)$$

The system from Fig. 1 with application of OR resembles a multidimensional teletraffic system called “shearing with call limitations” [18], where all traffic flows have full access to the common resources, but some or all of the traffic flows can occupy only limited number of these resources. For system with call limitations the convolution method is giving an exact solution. Unfortunately in our system every Wi-Fi flow have reserved “own” resources that can not be used by the neighboring Wi-Fi subscribers leading to not exact results by the convolution method. Only for the case $k = 1$ the convolution method is exact one. The simulation in [14] for a similar teletraffic system (k = 6) shows the error of convolution method application is acceptable for practical network design purposes.

Numerical Results

The current section is dealing with an analytical evaluation on the effect of accommodating the WiFi overflow traffic by a WiMAX cell, applying both the SO and OR traffic control algorithms. The system we are considering (depicted on Fig. 1) consists of a single WiMAX cell with a wide coverage area, which covers a total of 10 WiFi cells with much smaller coverage, each having a resource size of simultaneously serving 6 calls, and an equal offered traffic load A_i in range of 0.5 to 12 erl. The traffic flows to the WiFi AP resources and the direct flow to the WiMAX resources are all Poisson and independent of each other. The overall offered traffic load of the system is a summation of these independent flows.

Since the WiFi bandwidth resources are cheaper compared to the WiMAX ones, it is preferred the user to choose the WiFi for network access and when a call to a WiFi cell is blocked due to occupation of the cell resources, the call to be rerouted to the WiMAX cell. Fig. 2 depicts the overall carried traffic of the system as a function of applying an appropriate traffic control algorithm, considering different values of WiMAX resources n_{WMAN}. In this case, we assume no direct traffic load A_{WMAN} to the WiMAX cell. The same figure also depicts the impact of having the WiMAX resources as a backup of WiFi in terms of the overall carried traffic.

The second point of the analysis, presented at Fig. 3, is dealing with the calls from users, situated outside the WiFi coverage, who are directly served by the WiMAX cell. In this case, there is a direct traffic load A_{WMAN} to the WiMAX cell. For the purpose of the analysis, we assume A_{WMAN} to be three times greater than the traffic load offered to each WiFi cell. As one can see from the results, applying the OR algorithm can significantly improve the overall network performance.

Conclusion

We have presented an integrated WLAN/WMAN architecture based on IEEE 802.11 and IEEE 802.16 standards and specifically proposed an algorithm for voice traffic call control. We have proposed analytical models for system throughput evaluation and verified the effectiveness of using WMAN as a backup for WLAN overflow traffic and the proposed call rearrangement algorithm.

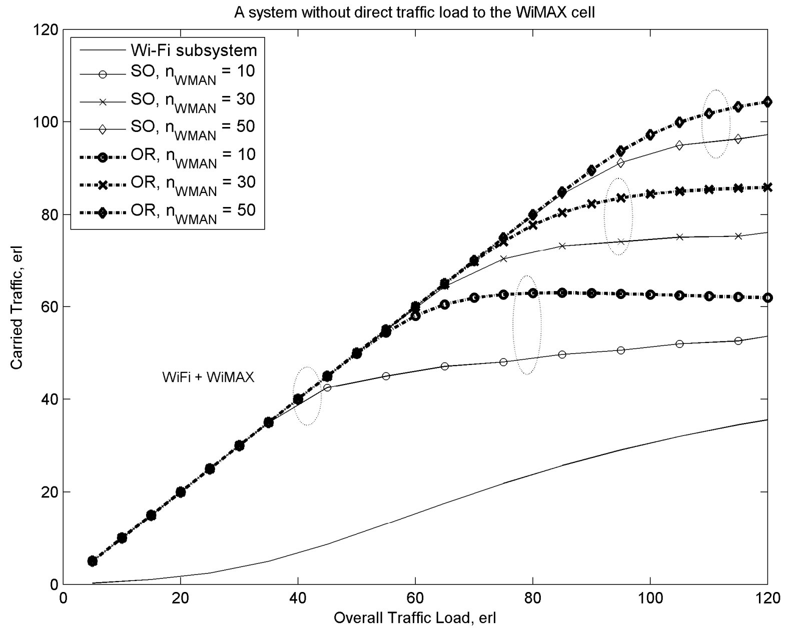

Fig. 2 Overall carried traffic, considering a system without direct traffic load to the WiMAX cell

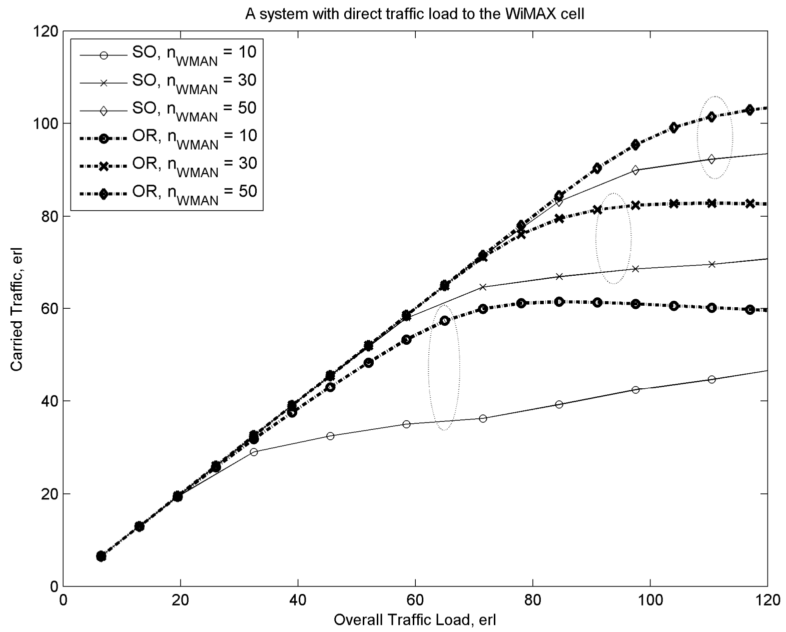

Fig. 3 Overall carried traffic, considering a system with direct traffic load to the WiMAX cell

Acknowledgement

This work was supported by the Bulgarian Ministry of Education and Science with grant ВУ-ТН-105/2005 (project "Multimedia Packet Switching Networks Planning with Quality of Service and Traffic Management" and by the Technical University of Sofia – grant 080910dni-7 (project "Optimal Telecommunications Resource Allocation with Cross-Layer Design")

Bibliography

[1] www.wi-fi.org

[2] IEEE 802.11 Working Group, IEEE 802.1-2007: LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 12.06.2007.

[3] www.wimaxforum.org

[4] IEEE 802.16e-2005, IEEE standard for local and metropolitan area networks – Part 16: Air interface for fixed and mobile broad band wireless access systems – Amendment for physical and medium access control layers for combined fixed and mobile operation in licensed bands, May 20, 2005, http://ieee802.org/16/pubs/80216e.html.

[5] N. Fourty, T. Val, P. Fraisse and J.-J. Mercier, Comparatice analysis of new high data rate wireless communication technologies "From Wi-Fi to WiMAX", Proc. of Joint Int. Conf. on Automatic and Autonomous Systems and Int. Conf. on Networking and Services (ICAS/ICNS 2005), Oct. 2005, pp. 68-68.

[6] B. Tsankov, Routing tree branch evaluation in WiMAX multi-hop network for voice traffic, Proc. of Nat. Conf. with Int. Particip. ELECTRONICS 2008, Sofia, 29 – 30 May, (submitted for presentation).

[7] H.-Y. Wei and R. D. Gitlin, Two-hop-relay architecture for next-generation WWAN/LAN integration, IEEE Wireless Communications, vol. 11, n. 2, Apr. 2004, pp.24 – 30.

[8] H.-Y. Wei and R. D. Gitlin, Incentive scheduling for cooperative relay in WWAN/LAN two-hop-relay network, Proc. Of IEEE Wireless Communications and Networking Conf., WCNC 2005, vol. 3, pp. 1696 – 1701.

[9] R. Giuliano, M. Luglio and F. Mazzenda, Interoperability between WiMAX and broadband mobile space networks, Communications Magazine, vol. 46, n. 3, March 2008, pp. 50-57.

[10] S Jindal, A. Jindal and N. Gupta, Grouping Wi-MAX, 3G and Wi-Fi for wireless broadband, Proc. of First IEEE and IFIP Int. Conf. in Central Asia on Internet, Sept. 2005, pp. 1-5.

[11] P. Neves, S. Sargento and R. L. Aguiar, Support of real-time services over integrated 802.16 metropolitan and local area networks, Proc. of 11th IEEE Symposium on Computers and Communications (ISCC'06), Oct. 2006, pp. 15-20.

[12] H. Pan, S. Yamamoto, D. Kawasaki and H. Tani, Capacity analysis and resource management of an integrated WiMAX and WiFi access system for VoIP, Proc. of 2nd Int.Conf. on Access Networks $ Workshops 2007, AccessNet'07, pp.1-8

[13] S. T. Gul, C. Moy and J. Palicot, Two scenarios of flexible multi-standard architecture designs using a multi-granularity exploration, Proc. of 18th IEEE Int. Symp. On Personal, Indoor and Mobile Radio Communications (PIMRC'07), 2007, pp. 1-5.

[14] B. Tsankov and R. Pachamanov, Performance evaluation of an umbrella-cell in cell networks. Proc. of TELECOM 2006, St. Konstantin and Helena - Varna, Oct. 2003, (in Bulgarian)

[15] B. Tsankov and Ts. Slavova, Traffic in telecommunications networks and systems, „Tehnika", Sofia, 1979, (in Bulgarian).

[16] V. B. Iversen, Teletraffic Engineering Handbook, ITU-D, Geneva, 2003

[17] B. Tsankov, Telecommunications – fixed, mobile and IP, "Novi znania", Sofia, 2006, (in Bulgarian)

[18] B. Tsankov, R. Shishkova, Teletraffic Models of a Common Trunk Group Serving ISDN-Traffic. Proc. of 2nd Int. Sem. on Teletraffic Theory and Computer Modeling, Moscow, Oct., 1989, vol. 3, pp. 22-41.

Authors' Information

Boris Tsankov – Associate Professor, Technical University - Sofia, 8th, Kl. Ohridski Blvd, 1000 SOFIA, Bulgaria; e-mail: bpt@tu-sofia.bg

Kiril Kassev – Assistant Professor, Technical University - Sofia, 8th, Kl. Ohridski Blvd, 1000 SOFIA, Bulgaria; e-mail: kmk@tu-sofia.bg

Radostin Pachamanov – Solution Engineer, Ericsson Telecommunications Bulgaria, 55, N. Vaptsarov Blvd., 1407 SOFIA, Bulgaria; e-mail: radostin.pachamanov@ericsson.com