ON WIRELESS RESOURCE ALLOCATION IN NETWORKS USING SOFTWARE DEFINED RADIO

Motoko TANIGUCHI (Div. of Comp. And Elec. Eng., Faculty of Eng., Yokohama National University, Yokohama, Kanagawa, JAPAN; motoko-t @kohnolab.dnj.ynu.ac.jp); Kenta UMEBAYASHI (University of Oulu Centre for Wireless Communications, Oulu, FINLAND; ume@ee.oulu.fi); Takenori SAKAMOTO, Katsuaki ABE, Takeshi MATSUOKA (Broadband Communications Dev. Center, Corporate Network Dev. Div., Matsushita Electric Industrial Co., Ltd., Shinagawa, Tokyo, JAPAN; [sakamoto.takenori, abe.katsuaki, matsuoka.takashi @jp.panasonic.com) and Ryuji KOHNO (Div. of Comp. And Elec. Eng., Faculty of Eng., Yokohama National University, Yokohama, Kanagawa, JAPAN; kohno@ynu.ac.jp)

ABSTRACT

Since there is no compatibility between the existing different communication systems, networks must be independently constituted in a present day. However, a network can be constituted, even when different communication systems are used together, by using a software defined radio (SDR) function in the base station of a network. Here, if SDR is put into practical use, it is possible that conventional terminals, whose communication systems are fixed and terminals with the SDR functions are both used in a communication environment. In this network, when a base station controls the wireless resources of all terminals, communication while considering the influence of mutual communication is realizable and improvement in the throughput of the network can be expected. In this paper, the resource allocation method in a base station is considered, and the throughput in a network of Wireless LANs is analyzed.

1. INTRODUCTION

Software Defined Radio (SDR) [1], [2], which has the ability to change radio functions by change altering the software, regardless of the hardware, is currently observed and is in an advanced stage [3]. Since it can respond to a number of communication systems using this characteristic, using SDR in a base station is conventionally studied. Although various communication systems exist in the present day, there is still incompatibility due to the independent operation of each system. However, in SDR, even if different communication systems are used concurrently, if the base station is SDR, each system can connect to each other by relaying through the SDR Base Station (SDR BS).

For example, Wireless LAN such as IEEE 802.11a, and 802.11b, whose frequency bands and modulation schemes are different from each other, require networks to be constituted independently. However, communication between different systems is possible by adding a base station with SDR BS as a composite element of a network.

Additionally, considering IEEE 802.11b and IEEE 802.11g, where the same network can be constituted from setting an access point to IEEE 802.11g, there is a problem that the access speed of the IEEE 802.11g terminal falls. However, communication of different systems is attained by adding a base station with the SDR function as a composite element of a network. If the base station can respond to both IEEE 802.11b and IEEE 802.11g, it will also be possible that it can communicate without reducing access speed.

The SDR BS in such an environment needs to change radio functions according to the terminals of different communication systems. Here, if SDR is put to practical use, it is possible that conventional terminals, whose communication systems are fixed, and terminals with the SDR function (henceforth, SDR terminals) can be concurrently used in a communication environment. Unlike conventional terminals, SDR terminals can change their radio functions. Therefore, when the SDR BS controls the communication system of the SDR terminal based on the number of and communication systems contained in conventional terminals, analysis of the influence of mutual communication can be performed, and improvement in the quality of the network can be expected.

In this paper, the communication control algorithm of terminals in the SDR BS in an environment where conventional terminals and SDR terminals are used together is examined. The controllable radio resources in the SDR BS include the communication time with every terminal and the communication systems of the SDR terminal. First, the data rate used by each communication system is chosen

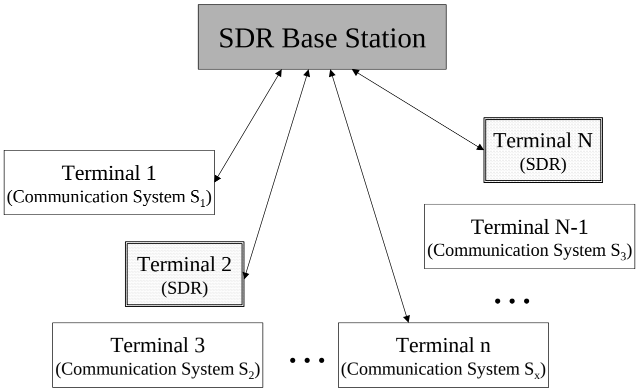

Fig. 1 Network Model

from the allowed BER maximum of terminals and channel quality information. Next, the time distributions in the SDR BS for every terminal and the communication systems of the SDR terminals are derived subject to the request for time allocation minimum value. It is shown that the throughput characteristic in governed by this control method. Moreover, the indicator for maximizing the throughput is shown.

This paper is organized as follows: In Sect. 2, assumed network model is sown. In Sect. 3, parameters used in the proposal algorithm are explained. In Sect. 4, analysis of the assumed network is shown. In Sect. 5, the communication system of the SDR terminal and communication time allocation algorithm in the SDR BS is presented. In Sect. 6, it is verified in a wireless LAN network. Finally, conclusions and future research subjects are given in Sect. 7.

2. NETWORK MODEL

In this paper, the network, which consists of one SDR BS and N terminals (terminal 1, 2, …, n, …, N), is assumed (Figure 1). It is assumed that base station has SDR function and N terminals, which include conventional terminals and SDR terminals. Let G express this network, S is the set of communication systems in G, and M is the set of combinations among elements of S.

$$G = (S, M)$$
$$S = \{s_1, s_2, \cdots, s_x \mid x \leq N\} \quad (1)$$
$$M = \{m_1, m_2, \cdots, m_y \mid y \leq N!\}$$

The number of elements of S, s_i, becomes N (the maximum number) when all N terminals use different communication systems respectively. The m_i, element of M, expresses combinations, m_i =(communication system of the terminal 1, communication system of the terminal 2, …, communication system of the terminal N). The value of s_i depends on the number of conventional terminals, and the value of m_i depends on the number of SDR terminals.

The Structure of this network changes with combinations of communication systems of terminals. Therefore, we'll propose that SDR BS control resources of terminals based on the number of terminals and combinations of communication systems. In this paper, we discuss the case of downlinks that is from SDR BS to terminals for simplicity.

3. ASSUMPTIONS OF ASSIGNMENT

3.1. Assignment Objects

In the network as shown in Figure 1, depending on the communication system of the destination terminal, SDR BS needs to reconfigure its communication system. Here, both the SDR terminal and SDR BS can choose their communication system. Therefore, the SDR BS can choose the communication system with the SDR terminal adaptively according to the situation of the other conventional terminals. By estimation of the quality of the channel, the SDR BS can also control data rate in the terminals.

Wireless resources, which are assigned to terminals in the SDR BS, are as follows;

(1) Communication time with all terminals
(2) Communication system in SDR terminals
(3) Data rate of all terminals

3.2. Parameters Used in Assignment

Table 1. Parameters Used in Assignment

The number of terminals	N(n=1, 2, …, N)
Allowed BER maximum value	Pemax_n
CNR estimated value	CNR_n
Connection time	Ts_n,mi
Reconfigure time	Tr_n,mi
Data rate	B_n,mi
BER under data rate B_n,mi	Pe_n,mi
Time of 1 cycle	T
Required time allocation ratio minimum value	amin_n
Required time allocation ratio maximum value	amax_n

Parameters used in assignment are shown in Table 1. Here, subscripts of each parameter are explained as follows. Parameters, which have only subscript n, depend on the kinds of data or request to the terminal, and are the eigen-value of the terminal. Parameters, which have subscript n

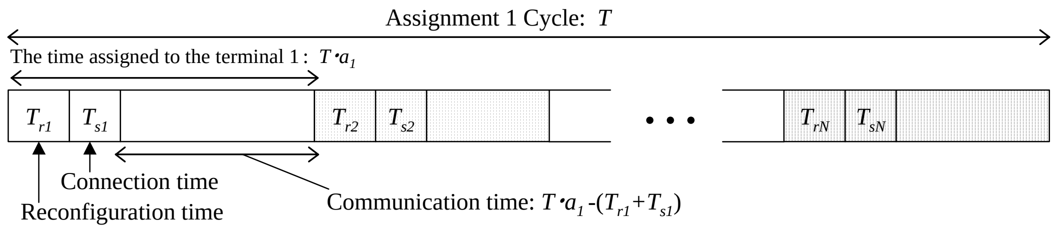

Fig. 2 Time Allocation in SDR Base Station

and mi, depend on the communication system of the terminal and the combination of communication systems in the network. This means that values change according to circumstances in each terminal.

- Allowed BER maximum value: Pemax_n

This shows the maximum of the bit error rate which is allowed by the terminal n.

- CNR estimated value: CNR_n

It is assumed that the SDR BS can estimate the channel situation. CNR_n means the estimated CNR value of the channel to the terminal n.

- Connection time: Ts_n,mi

This means the time that the SDR BS takes to connect with the terminal n. This depends uniquely on the communication system of terminal n.

- Reconfigure time: Tr_n,mi

This means the time that the SDR BS takes to reconfigure its wireless functions for communication with terminal n. This depends uniquely on the communication system of the terminal n.

- Data rate: B_n,mi

This means the data rate of terminal n. Bit error rate, Pe_n,mi, depends on B_n,mi.

3.3. Assignment Cycle

In consideration of communication comparison fairness, 1 cycle in defined as the length of that a SDR BS has for one communication to every terminal, e.g. every terminal can communicate with the SDR BS at once in a cycle.

The ratio of time assigned to each terminal during 1 cycle is defined as *a_n*. The time assigned to the terminal n in 1 cycle is $T \cdot a_n$. Here, as requests to terminal n, following requests about a_n are defined.

- Required time allocation ratio minimum value: amin_n
- Required time allocation ratio maximum value: amax_n

The time length of 1 cycle, T, uses a suitable value according to the number of terminals. Let a unit of time define T_c, T is represented as follows.

$$T = \sum_{n=1}^{N} (T \cdot a_n) = T_c \cdot N \qquad (2)$$

4. ANALYSIS OF THE SDR NETWORK

4.1. Time Allocation in SDR Base Station

If communication systems of terminals are different, SDR BS is required to repeat a reconfiguration of communication system, connection with a terminal, and data transmitting. A time allocation in the SDR BS when the network is consisted of N terminals is as shown in Figure 2.

4.2. Throughput

When the combination of N terminals' communication systems are m_i in the network *G*, let the throughput *TH_mi* denote as follows.

$$TH\_m_i \text{ [bps]} = \frac{\text{Total data transmitted correctly [bit]}}{\text{The time length of 1 cycle [sec]}}$$

Breakdown of $T \cdot a_n$, the time assignment for the terminal n in a cycle, is as Figure 2. Therefore, the data number transmitted to the terminal n with data rate, B, in $T \cdot a_n$ is

$$th_{n,m_i} = B_{n,m_i} \left(1 - Pe_{n,m_i}\right) \left\{T \cdot a_n - \left(Tr_{n,m_i} + Ts_{n,m_i}\right)\right\} \qquad (3)$$

Total throughput (N terminals) is expressed as follows.

$$TH_{m_i} = \left\{ \sum_{n=1}^{N} th_{n,m_i}(a_n) \right\} \Big/ T \qquad (4)$$

4.3. Terminal QoS

Terminal satisfaction with the time allocation ratio assigned is evaluated as terminal QoS. Using amin_n, required time allocation ratio minimum value, and amax_n, required time allocation ratio maximum value, terminal QoS is as follows.

$$Q_n = \begin{cases} 1 & a_n = a_{\max_n} \\ \dfrac{a_n - a_{\min_n}}{a_{\max_n} - a_{\min_n}} & a_{\min_n} \le a_n < a_{\max_n} \\ -\infty & otherwise \end{cases} \qquad (5)$$

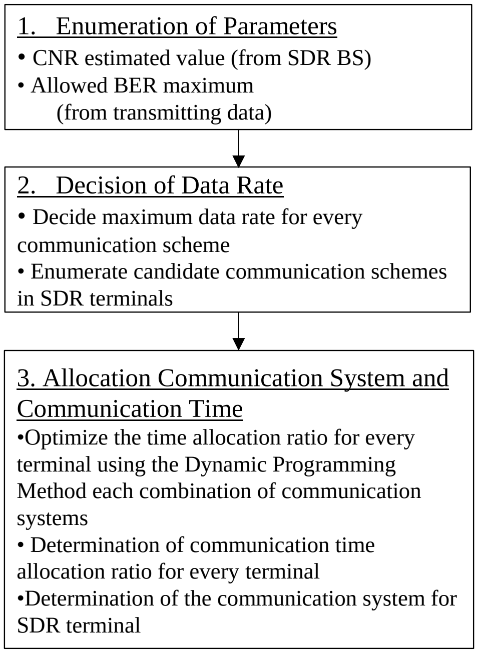

Fig. 3 Allocation Algorithm

5. ALLOCATION ALGORITHM

In this section, Algorithm that control the communication time between the SDR BS and every terminal, as well as the communication system of the SDR terminals is proposed.

5.1. Algorithm

Allocation algorithm for the communication time and the communication system of SDR terminals is shown in Figure 3 and follows.

1. SDR BS estimates CNR value between BS and terminals, and gets CNR_n for every terminal.
2. SDR BS searches *S*, which is the set of communication systems in *G*, and *M*, which is the set of combinations among elements of *S*. Here, candidate of communication systems for SDR terminal are enumerated.
3. Maximum data rate for every communication system, which satisfies the following equation, is selected.

$$Pe_{n,m_i}\left(CNR_n\right) \le Pe_{\max_n} \qquad (6)$$

4. Determine the aim of optimization in the network, and optimize the time allocation ratio a_n for every terminal using the Dynamic Programming Method [4] each m_i. Optimization is subject to amin_n, which is the required time allocation ratio minimum value. Choose the combination which most satisfy the aim, here, the communication of SDR terminals are determined.

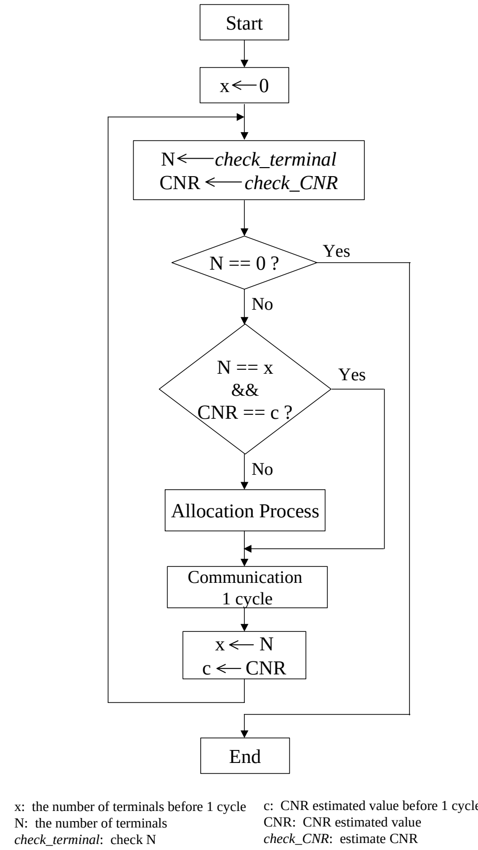

Fig. 4 Allocation Flow in SDR BS

5.2. Flow in SDR Base Station

SDR BS performs the allocation described previously by the flow as shown in the Figure 4. SDR BS searches CNR_n and the number of terminals in each cycle, if they change from previous cycle, re-performs the allocation. A change in the number of terminals is considered, since it could decrease by having a terminal finishing data transmission, or increase by having a new terminal starting data transmission.

6. VERIFICATION UNDER WIRELESS LAN NETWORK

In this section, we verify the proposed algorithm in network using Wireless LAN.

6.1. Network Model

It is assumed that there are a SDR BS, and 10 terminals. Communication systems used in the network are IEEE 802.11a and IEEE 802.11b. Terminals are some

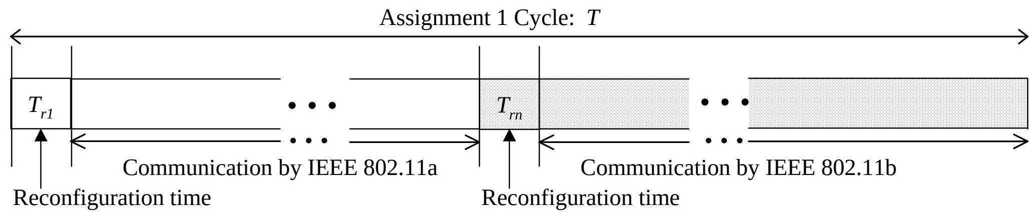

Fig. 5 Time Allocation in SDR BS Under W-LAN Network

conventional terminals and SDR terminals. Data is transmitted to terminals from SDR BS.

Here, this network is expressed as follows using Eq. (1).

$$G = (S, M)$$
$$S = \{s_1 = IEEE802.11a, s_2 = IEEE802.11b\}$$
$$M = \begin{Bmatrix} m_1 = (s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1), \\ m_2 = (s_2, s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1), \\ m_3 = (s_2, s_2, s_1, s_1, s_1, s_1, s_1, s_1, s_1, s_1), \\ \cdots \\ m_{10} = (s_2, s_2, s_2, s_2, s_2, s_2, s_2, s_2, s_2, s_2) \end{Bmatrix} \tag{7}$$

6.2. Time Allocation in SDR Base Station

Time allocation in SDR BS is shown in Figure 5.

SDR BS needs reconfiguration time when it switch to IEEE 802.11a from IEEE 802.11b, or to IEEE 802.11b from IEEE 802.11b. In this paper, the order of terminals is decided that make reconfiguration time minimum.

6.3. Application of Dynamic Programming Method

It is shown the optimization of time allocation ratio for each terminal whose aim is maximizing the total throughput in 1 cycle in the network using Dynamic Programming Method. From Eq. (3) and (4), the allocation problem is represented as follows.

$$\begin{aligned} & f_N(k_N) = \max[TH_N] \\ & TH_N = \left\{ \sum_{n=1}^{N} th_n(a_n) \right\} \Big/ T \\ & th_n(a_n) = B_n \cdot (1 - P_{e_n}) \cdot \{T \cdot a_n - (T_{r_n} + T_{s_n})\} \\ & N = 10 \end{aligned} \tag{8}$$

Subject to

$$\begin{aligned} & k_N = \sum_{n=1}^{N} a_n = 1 \\ & a_n \geq a_{\min_n} \end{aligned} \tag{9}$$

These are expressed following recursive equations, and it is possible to use Dynamic Programming Method.

$$\begin{cases} f_n(k_n) = \max[th(a_n) + f_{n-1}(k_n - a_n)] & (n = 2, 3, \cdots, 10) \\ f_1(k_1) = \max[th_1(a_1)], a_1 = k_1 & \end{cases} \tag{10}$$

6.3.1. Simulation Parameters

Table 2. Simulation Parameters

Communication system	IEEE 802.11a	IEEE 802.11b
Allowed BER maximum value	10^{-5}	10^{-5}
CNR estimated value	12dB	20dB
Data rate	24Mbps	11Mbps
BER	$5.1*10^{-9}$	$5.6*10^{-8}$

Parameters used in verification are shown in Table 2. For simplicity, CNR estimated value and allowed BER maximum value are same for each communication system.

Using a receiver sensitivity performance of IEEE 802.11a and IEEE 802.11b technical standard, under parameters of Table 2, data rate and BER under the data rate are derived as shown in Table 2 [5][6].

6.3.2.Total Throughput in 1 Cycle

A total throughput in 1 cycle is shown in Figure 6. It increases with the growth of the number of IEEE 802.11a terminals. The time allocation ratio is optimized, and it is shown that the total throughput maximization is attained. This gives suggestions to switching the communication systems of SDR terminals.

6.3.3 Terminal QoS

Average Terminal QoS is shown in Figure 7. Both IEEE 802.11a and IEEE 802.11b change by optimization of the time allocation ratio. Since the aim is to maximize the total throughput, terminals of IEEE 802.11a that have bigger data rate than IEEE 802.11b are given communication time more than terminals of IEEE 802.11b.

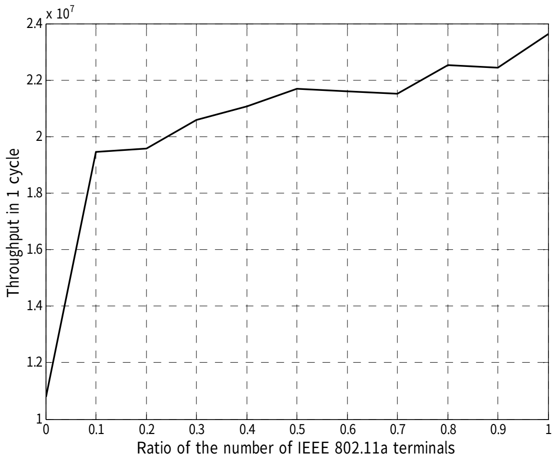

Fig. 6 Total Throughput in 1 Cycle

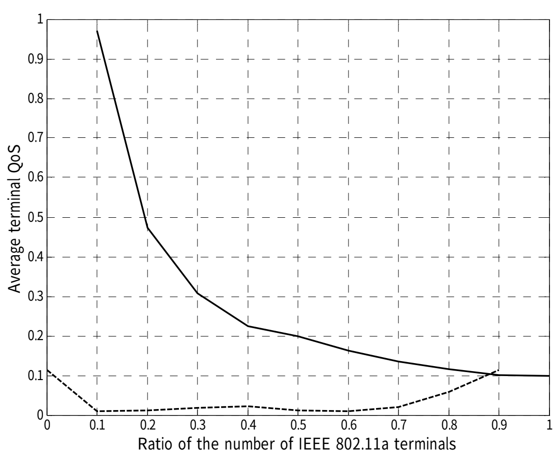

Fig. 7 Average Terminal QoS

7. CONCLUSIONS

In this paper, the communication control algorithm of terminals in the SDR BS in an environment where conventional terminals and SDR terminals are used together is proposed. It is shown that improvement in the throughput of the network can be expected using the proposed algorithm.

When the aim of optimization is only maximizing the total throughput in 1 cycle in the network, there is difference in terminal QoS. Therefore, It turns out that the assignment, which also considers terminal QoS simultaneously with throughput, is required. This is our future work.

8. REFERENCES

[1] J. Mitola, "Software Radio," *IEEE Commun. Mag.*, pp. 24-38, May 1995.

[2] J. Mitola, "Software Radio Architecture: A Mathematical Perspective," *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 4, pp. 514-538, April 1999.

[3] F. WATANABE, M. OHASHI, H. NAKAMURA, H. IWAI, "Expectation on Software Defined Radio (SDR) in Standardization Fora on Future Mobile Communication System," IEICE Trans. Commun., Vol.E86-B, No.12, Dec. 2003.

[4] Tomoharu Nagao, "Optimization Algorithm," 2000.

[5] "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification: High-speed Physical Layer in the 5 GHz Band," IEEE Std 802.11a, 1999.

[6] "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification: Higher-speed Physical Layer Extension in the 2.4 GHz Band," IEEE Std 802.11b, 1999.

[7] J. WU, R. KOHNO, "Performance Evaluation of Wireless Multimedia CDMA Networks Using Adaptive Transmission Control," IEEE J. Sel. Areas Commun., vol.14, no.9, Dec. 1996.

Copyright Transfer Agreement: The following Copyright Transfer Agreement must be included on the cover sheet for the paper (either email or fax)—not on the paper itself.

"The authors represent that the work is original and they are the author or authors of the work, except for material quoted and referenced as text passages. Authors acknowledge that they are willing to transfer the copyright of the abstract and the completed paper to the SDR Forum for purposes of publication in the SDR Forum Conference Proceedings, on associated CD ROMS, on SDR Forum Web pages, and compilations and derivative works related to this conference, should the paper be accepted for the conference. Authors are permitted to reproduce their work, and to reuse material in whole or in part from their work; for derivative works, however, such authors may not grant third party requests for reprints or republishing."

Government employees whose work is not subject to copyright should so certify. For work performed under a U.S. Government contract, the U.S. Government has royalty-free permission to reproduce the author's work for official U.S. Government purposes.