A UNIFIED WIRELESS PLATFORM ARCHITECTURE FOR A WIDE VARIETY OF WIRELESS SYSTEMS

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ABSTRACT

A great variety of wireless systems are currently being used to provide diverse and sophisticated information and communication services. New wireless systems are being standardized for later implementation. In addition, large numbers of radio-frequency identification (RFID) terminals and sensors are being installed everywhere to implement a ubiquitous society. As wireless systems and wireless terminals continue to grow in both number and variety, this will cause a number of problems such as a lack of suitable locations for installing base stations and inter-system interference. To solve these problems, we propose a new flexible wireless system that uses software defined radio technology and cognitive radio technology to support a wide variety of wireless systems. The system processes all received radio waves with network software. A prototype of the system was developed to confirm its effectiveness. We also propose a highly efficient software demodulating method and show its effectiveness by evaluating it with the system prototype.

1. INTRODUCTION

A wide variety of wireless systems are used to achieve a ubiquitous society that enables anyone or anything to access networks and use the information the networks provide anytime and anywhere. People can already use cell phones and wireless LANs to obtain ubiquitous services. Such services can be enhanced through the use of WiMAX, long-term evolution (LTE) and 4G systems. In addition, the use of sensors and radio-frequency identification (RFID) makes it possible to procure ubiquitous services for machines, including logistics and security services. As information and communication services become more sophisticated and diversified, we are likely to see an explosion in the number of sensors and RFID terminals [1][2]. However, the increased diversity and number of wireless systems causes problems such as inter-system interference and a lack of suitable base station installation locations. Moreover, in the future these problems will certainly become more severe since wireless systems need to support an enormous number of wireless terminals.

In light of this background, we previously proposed a network concept for a ubiquitous society that can handle any applications by adapting network functions to terminal specifications [3]. We also proposed a wireless system that supports multiple wireless systems and autonomously manages base station hardware resources subject to the availability of each of the wireless systems. In this paper we propose a flexible wireless system we have developed that uses software defined radio technology and cognitive radio technology. The system is a unified wireless platform that supports a wide variety of wireless systems. Its main feature is that it stores all received radio waves in a network and processes them with software. Thus, as opposed to conventional wireless systems, the waves do not need to be processed at a base station.

The rest of the paper is organized as follows. Section 2 describes the system in detail. Section 3 shows the design and performances of a system prototype. Section 4 concludes the paper with a brief summary of the main points.

2. FLEXIBLE WIRELESS SYSTEM

We used the three design concepts listed below to construct a flexible wireless system that can efficiently support a wide variety of wireless systems and an enormous number of wireless terminals.

1. Support for transmitting and receiving radio waves of any frequency band
2. Efficient support for an enormous number of wireless terminals
3. Support for adding, removing, and updating wireless protocol software that operates as a wireless system

Figure 1 shows a conceptual diagram of our new system. It is composed of a band-free radio frequency (RF) part and a protocol-free base band (BB) processing part. Both parts are connected via an access network such as an optical fiber network [2]. Radio over fiber (ROF) is the technology it uses for transmitting radio signals converted to light signals. In references [5]-[8], ROF was used for service area expansion. References [10] and [11] reported an optical feeder transmitter and receiver type base station in which antenna equipment is connected to modulation and demodulation equipment by an optical fiber network. The “Fiber optic networks for distributed and extendible heterogeneous radio architectures” (FUTON) project, one of the projects funded under the seventh framework program (FP) of the European Union (EU), has proposed the development of a hybrid fiber radio infrastructure transparently connecting remote antenna units to a central unit where joint processing can be performed. The object of the FUTON project is to achieve broadband wireless transmission and inter-cell interference cancellation for 4G systems. The main difference between these researches and our study is that our proposed system supports transmission and reception in a wide variety of systems simultaneously. The broadband property is required for the antenna and RF circuit of the band-free RF part of our system because it needs to transmit and receive radio signals regardless of the frequency band (see Fig.1). One problem is that there is a large difference in the signal power level in the band-free RF part due to its need to support different wireless protocols. It thus needs to provide a highly dynamic range performance. On the other hand, its protocol-free BB processing part is installed in a network and collectively processes transmitted signals from multiple band-free RF units by means of software. Since it uses the software process to execute a wireless protocol, it can accommodate a new wireless protocol and update its functions merely by adding and updating software. Moreover, it is expected to include a statistical multiplexing effect that will enable it to centralize many functions that are normally executed individually in a large number of base stations. This helps it to support a great number of wireless terminals efficiently.

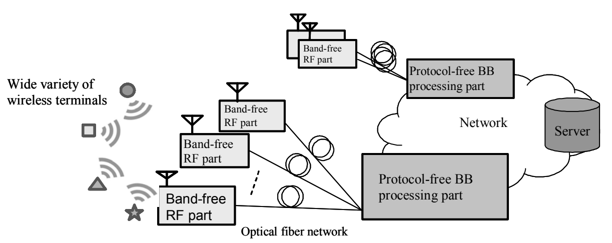

Fig. 1 Conceptual diagram of system

3. FLEXIBLE WIRELESS SYSTEM PROTOTYPE

3.1 Prototype configuration and functions

We developed a prototype of the system to ascertain its practicality. An active RFID system was chosen as a wireless protocol operated by the prototype. It should be noted that there are many kinds of active RFID systems because frequencies, transmission rates, and communication protocols differ for each manufacturer. Typical frequency bands assigned to RFID systems include the 300 MHz, 430 MHz, 950 MHz, and 2.4 GHz bands. Figure 2 shows an overview of a prototype for our system and the prototype specifications are summarized in Table 1. The prototype supports frequencies from 280 MHz to 322 MHz and from 2.4 GHz to 2.442 GHz. As the figure shows, signals received in the band-free RF part are converted from analog to digital form. The converted signals are then transmitted to the protocol-free BB processing part via a 10G BASE-T and processed. Meanwhile, transmission data is modulated in the protocol-free BB processing part and transmitted to the band-free RF part via the 10G BASE-T. Transmitted signals are then re-converted into analog form in the band-free RF part and transmitted as radio waves.

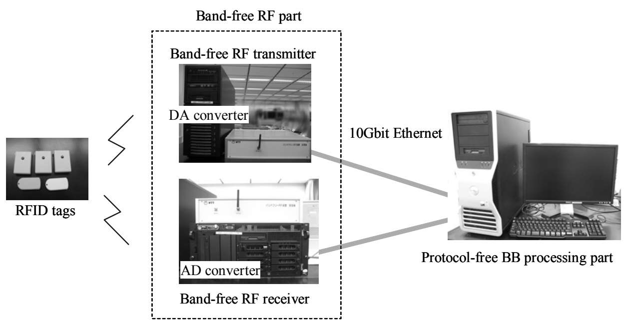

Fig.2 Prototype overview

Table 1 Prototype specifications

Band-free RF receiver	Frequency	280 MHz - 322 MHz, 2.4 GHz - 2.442 GHz
	IF band	1 MHz - 43 MHz
	Input power level	-80 dBm - -41 dBm
Band-free RF transceiver	Frequency	280 MHz - 322 MHz
	IF band	1 MHz - 43 MHz
	Transmission power	Low-power radio
Antenna	Shape	Helical whip (length 95 mm)
AD converter	No. of input channels	2
	Bandwidth	1 MHz - 43 MHz
	Resolution	16 bits
	Sampling rate	100 Msps
	NW interface	10G BASE-T

DA converter	No. of output channels	2
	Bandwidth	1 MHz - 43 MHz
	Resolution	16 bits
	Sampling rate	100 Msps
	NW interface	10GBASE-T
Protocol-free BB processing part	CPU	2.66 GHz Xeon (Quad core) * 2
	Memory	8 GB
	Chipset	Intel 5000X chipset
	OS	Windows server 2003 R2 Standard Edition

3.1.1 Band-free RF part

Band-free RF receiver

The band-free RF receiver uses front-end ICs for a receiver comprising a mixer and a broadband low noise amplifier (LNA), as shown in Fig. 3. The LNA shows good broadband frequency performance because of its S-parameter characteristic shown in Fig. 4 [12]. Figure 5 is a block diagram of the band-free RF receiver. Although it comprises a dual antenna, one for the 300-MHz band and one for the 2.4-GHz band, each received signal is down-converted to an Ich signal and a Qch signal of IF signals of 1 MHz to 43 MHz by using the same front-end receiver ICs. Figure 6 shows a reception front-end IC of the type that is mounted in a band-free RF receiver. Its chip size is 9 mm^2 and its noise figure and conversion gain performances are shown in Fig. 7. We obtained excellent results in this regard; the noise factor was less than 3 dB and the conversion gain was more than 22 dB over the broadband from 200 MHz to 2.5 GHz.

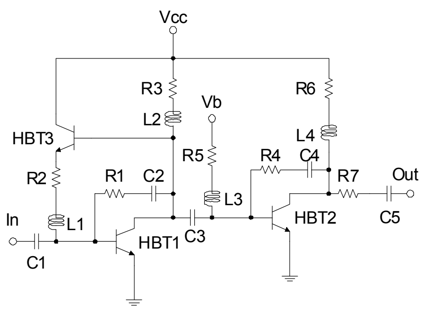

Fig. 3 Broadband LNA circuit diagram

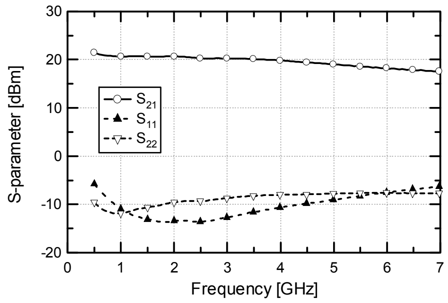

Fig. 4 S-parameter characteristic of broadband LNA

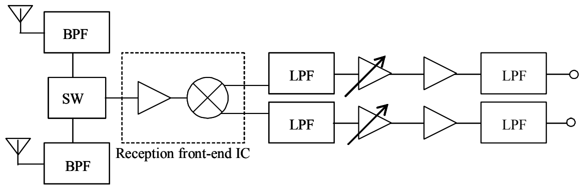

Fig. 5 Band-free receiver configuration

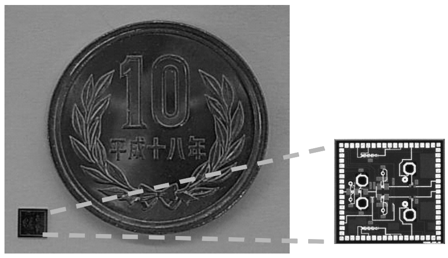

Fig. 6 Reception front-end IC

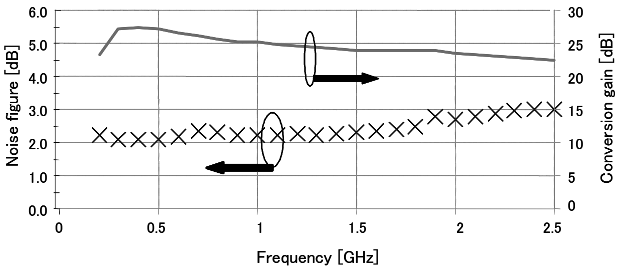

Fig. 7 Reception front-end IC performances

Band-free RF transmitter

The band-free RF transmitter up-converts input signals of from 1 MHz to 43 MHz to RF signals of from 280 MHz to 322 MHz. RF signals are transmitted according to the low power radio regulation. The transmitter uses a direct conversion method that basically does not output image signals as an up-conversion method.

AD/DA conversion part

Figure 8 shows the configuration of the AD/DA conversion part of the band-free RF part. The AD conversion part inputs analog signals converted to digital data and makes digital data IP packets. The packets are then sent to the protocol-free BB processing part by using the transmission control protocol (TCP). The AD/DA conversion part is connected to the protocol-free BB processing part via the 10G BASE-T. The DA conversion part takes digital data from the received IP packets. After converting the digital data to Ich and Qch analog signals, it outputs analog signals to the band-free RF transmitter.

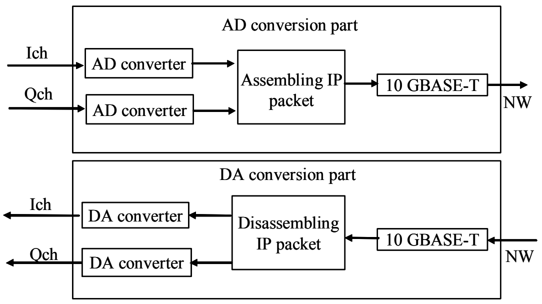

Fig. 8 Configuration of AD/DA conversion part

3.1.2 Protocol-free BB processing part

The wireless protocol software, which runs on the protocol-free BB processing part, includes many functions such as signal detection, demodulation, decoding, modulation, and encoding. The protocol-free BB processing part must detect signals from the radio waves received at the broadband, over which signals of multiple systems are superimposed, and demodulate them by using the correct wireless protocol's functions. Therefore, even though the band pass filter (BPF) is always being utilized and all the wireless protocols that the protocol-free BB processing part is handling are being demodulated, the result is an increase in the CPU processing load. To overcome this problem, we propose a highly efficient software decoding method that demodulates only when signals are detected. A flowchart of this method is shown in Fig. 9. At first, it analyzes the frequency of received signals and estimates their power level. If the power level at a frequency band exceeds a pre-determined threshold level, the BPF shapes the frequency band. Next, it selects wireless protocol candidates for which the frequency band is used. After the selection, the received waves are demodulated with the selected wireless protocol. Finally, the protocol is determined based on the demodulation result and the data is extracted. For evaluation purposes, the wireless protocol software we mounted in the prototype comprised the NIRE type 2 and NIRE type 3 software produced by NTT Advanced Technology Corporation (see Table 2). Although the current prototype supports only RFID tag systems, its hardware performance is also good enough to support wideband wireless communication systems. In addition, the prototype can easily support other wireless protocols merely by installing new wireless protocol software into it.

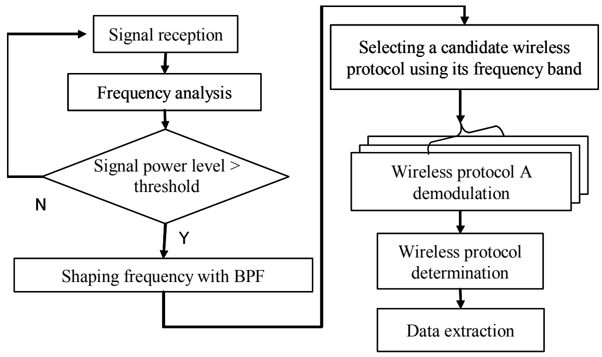

Fig. 9 Flowchart of our software modulating method

Table 2 NIRE type 2 and type 3 specifications

NIRE type 2	Frequency	312.2 MHz
	Modulation	OOK
	Transmission power	Low power radio
NIRE type 3	Frequency	310 MHz band
	Communication form	Bidirectional communication

3.2 Performance evaluation

We confirmed the operation of the band-free RF part when it received the RFID signals and also evaluated the CPU processing load in the protocol-free BB processing part as basic performance evaluations of the prototype.

3.2.1 RF reception performance

Three NIRE type 3 tags with differing center frequencies (i.e., 312.425, 313.025, and 313.625 MHz) transmit data. Figure 10 shows the signal spectrum of an RF band received by the system prototype. Figure 11 shows the IF band signal spectrum converted from 1 MHz to 43 MHz in the band-free RF part. Finally, Fig. 12 shows the BB band signal spectrum in the protocol-free BB processing part. It is clear that the band-free RF part can down-convert RF signals to IF signals without generating any unwanted signals when it receives the three signals as per the results in Figs. 10 and 11.

We also confirmed that our system prototype can convert RF signals to BB signals correctly when it receives multiple signals as per the results shown in Figs. 10, 11, and 12.

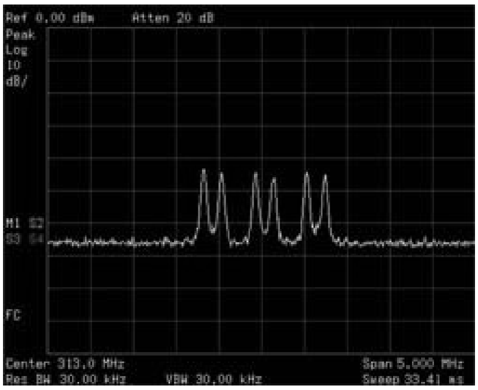

Fig. 10 Received signal spectrum at RF band

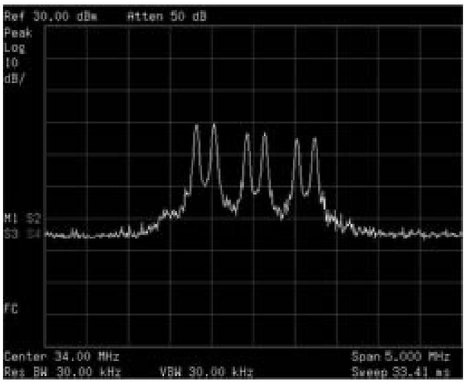

Fig. 11 Received signal spectrum at IF band

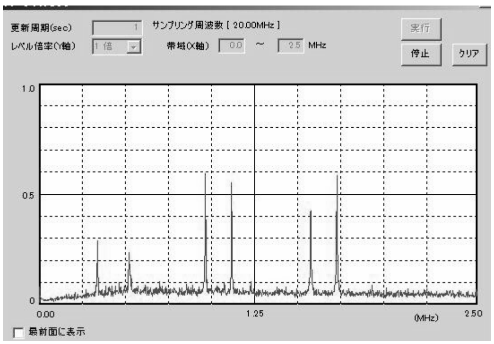

Fig. 12 A received signal spectrum at BB band

3.2.2 *Software demodulating method's CPU processing performance*

To clarify the effectiveness of our software demodulating method, we evaluated its CPU processing load by using the experimental model shown in Fig. 13. RFID tags and the antenna of the band-free RF part were set up in a shield box connected to the protocol-free BB processing part by using 10G BASE-T. Table 3 shows the RFID tag parameters used in the experiment. It is possible to make fifteen different kinds of RFID tags by combining the parameters shown in the table. In this experiment, we set the tag parameters such that they would differ. Figure 14 shows the relationship between the number of tags and the CPU processing load. When our method is not used, the modulation functions of all wireless protocols are executed regardless of whether signals are present or not. For the case in which there were 15 different RFID tag types and the average RFID tag interval was 100 ms, we found that our method was able to decrease CPU processing load by about 60%. From this we conclude that our system makes it possible to use the communication infrastructure more efficiently than for the case of setting up many kinds of dedicated wireless systems.

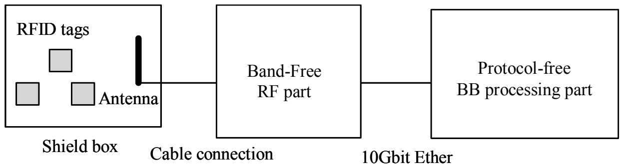

Fig. 13 Experimental model

Table 3 Experimental conditions

Tag	NIRE type 3
Modulation	FSK
Center frequency	312.425, 313.025, 313.625 MHz
Transmission rate	2.4, 4.8, 9.6, 19.2, 38.4 kbit/s

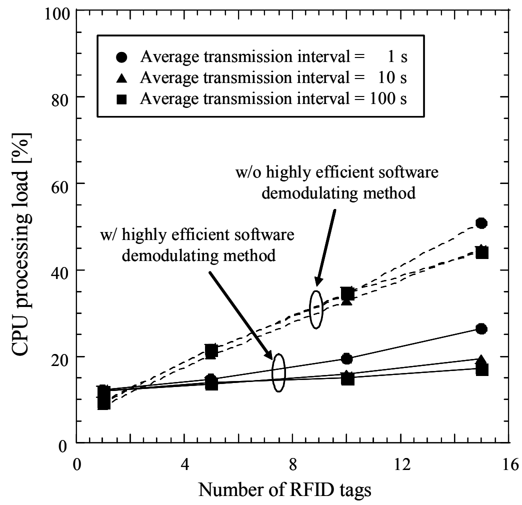

Fig. 14 Number of RFID tags vs. CPU processing load

4. CONCLUSION

We proposed a flexible wireless system comprising a unified platform that supports a wide variety of wireless systems by reproducing a radio wave environment over a network and processes the received signals with software.

Unlike a conventional wireless system, signals are processed without executing demodulation at a base station. The system is composed of a band-free RF part and a protocol-free BB processing part. We also developed a system prototype and evaluated its performance to confirm the system's practicality. The front-end ICs for a receiver that supports the 300-MHz to 3-GHz frequency band is implemented in the band-free RF part of the prototype. We also proposed a highly efficient software demodulating method and implemented it in the protocol-free BB processing part. Results of received signal spectrums at the RF, IF, and BB bands confirmed that the system operated in the manner that it was designed. Evaluation results made it clear that the highly efficient software demodulating method we propose can reduce CPU processing load compared with the case of not using it. The results we obtained lead us to conclude that our proposed system enables the communication infrastructure to be used more efficiently than in cases involving the setting up of many kinds of dedicated wireless systems.

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