A NOVEL MULTI-SERVICE SIMULTANEOUS RECEIVER WITH DIVERSITY RECEPTION TECHNIQUE BY SHARING BRANCHES

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ABSTRACT

In this paper, we propose a concept of a new receiver structure with diversity reception technique to realize multi-service simultaneous reception, which shares diversity branches between receiving communication services. In the proposed receiver structure, each diversity branch selects the receiving services dynamically according to channel states, and each communication service is always selected by at least one branch to realize multi-service simultaneous reception. A basic algorithm is also described to select combinations of a diversity branch and a receiving communication service. The total number of branches decreases and the effective number of branches per communication service increases, by sharing the branches between communication services in the proposed receiver. Simulation results are shown that the proposed diversity receiver achieves both complexity reduction and performance improvement.

1. INTRODUCTION

Multi-service simultaneous reception is one of the requirements for software defined radio for intelligent transport systems (ITS). Many communication services equipped on vehicles collaborate in ITS applications for safety and convenience, such as radio and television broadcasting, global positioning system (GPS), vehicle information and communication system (VICS), dedicated short range communications (DSRC), portable phone, and so on.

Multi-service simultaneous reception is also effective for vertical handover in the 4th generation mobile communication system, in order to switch the communication service seamlessly from a one to an alternative one. Moreover, multiple communication systems can be utilized in parallel as the request of heavy data traffic occurs.

In a conventional software defined radio for multi-service simultaneous reception, research interests have been usually focused on digital signal processing parts to deal with many kinds of communication systems alternatively or simultaneously. Thus, antennas and analog signal processing parts are usually assumed to be conventional ones in these studies.

On the other hand, diversity reception technique is often adopted to compensate fading effects in mobile communication environments. However, there is a problem that many diversity branches causes increase in hardware complexity.

In these years, studies about extending the capability of antennas and radio frequency (RF) front ends have attracted attention, such as wide-band and/or multi-band antennas, tunable RF filters, and so on. Then, we paid attention to what a receiver structure is suitable for such antennas and RF front ends, if they could be available.

In this paper, we propose a concept of a new receiver structure with diversity reception technique to realize multi-service simultaneous reception, which shares diversity branches between receiving communication services. In the proposed receiver structure, it is assumed that each diversity branch can receive one of the communication services temporarily. In selection diversity reception, a single diversity branch is used to demodulate received signal in a certain moment. Thus, the other diversity branches can be applied for other communication services at that moment. In maximal ratio combining diversity reception, the diversity branch whose received signal is weak does not contribute so much to the performance in a certain moment. Therefore, each diversity branch changes the receiving services dynamically from one to another one according to channel states, and each communication service to receive is always selected by at least one branch to realize multi-service simultaneous reception.

A basic policy is also proposed for the algorithm to select combinations of a diversity branch and a receiving communication service. Then, bit error performance of the proposed diversity receiver based on the algorithm is evaluated by computer simulation.

As a result, the total number of branches decreases and the effective number of branches per communication service increases, by sharing the branches between receiving communication services. Thus, it is shown that the proposed diversity receiver achieves both complexity reduction and performance improvement.

In Section 2, conventional approaches to realize multi-service simultaneous receiver are presented. In Section 3, we propose a new concept of multi-service simultaneous receiver. In Section 4, basic algorithm to select the diversity branches is described. In Section 5, simulation results are shown to evaluate the performance of the proposed receiver. Finally, we summarize the conclusion in Section 6.

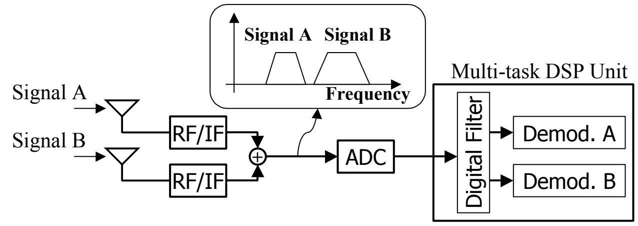
2. MULTI-SERVICE SIMULTANEOUS RECEIVER

One solution is an extraordinary wide-band receiver to realize multi-service simultaneous reception. It is a kind of ultimate software defined radio, in which the signal with the whole radio frequency band including all communication services is captured together and treated by digital signal processing (DSP) part.

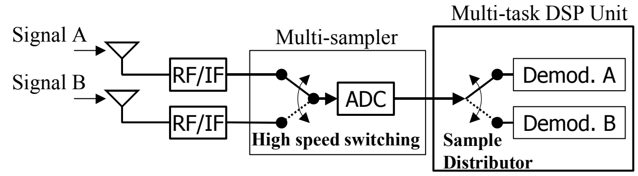
However, it is very difficult to realize because of many problems. For example, wide dynamic range and high sensitivity are required in analog signal processing part. An enormous number of bits and very high sampling rate are required in Analog-to-Digital converter (ADC). The large number of bits and the high sampling rate cause heavy computational load in DSP part. Therefore the signal with necessary and sufficient bandwidth should be only captured and treated.

There is another solution. Multi-service simultaneous reception is easy to be realized by preparing the same number of receivers as the number of communication services to receive simultaneously. In this case, the hardware complexity certainly increases in proportion to the number of services to receive simultaneously. Therefore, new receiver structure is necessary to realize multi-service simultaneous reception efficiently.

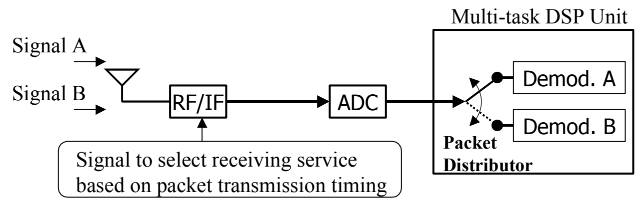
Sharability is an important feature in software defined radio to reduce hardware complexity. The DSP part is comparatively easy to share between different operations because of its re-configurability. In order to realize multi-service simultaneous reception efficiently for ITS systems, the concept of sharing DSP part between multiple services or operations has been investigated. Harada, et al., has proposed a ‘multi-mode and multi-service software radio communication system’ and ‘parameter-controlled software radio technology’ [1,2,3]. However these investigations are concerned with only DSP part, so analog signal processing part, such as antennas and RF front ends, is assumed to be the same as conventional one prepared for each communication service. Because the analog signal



(a) FDM approach: Multiplexing on IF band.



(b) TDM approach: Multi-sampler.



(c) TDM approach: Time sharing for packet data transmission.

Fig. 1: Conventional approaches to reduce hardware complexity on multi-service simultaneous reception.

processing part did not have so much wide capability to treat multiple communication services at that time.

After that, in order to reduce hardware complexity, the concepts of multi-service simultaneous receiver have been investigated, sharing not only DSP part but also analog signal processing part, such as antenna, RF front end, amplifier, down converter, ADC and so on. Moreover, extending the capability of analog signal processing part has been also investigated, such as wide-band and/or multi-band antennas, tunable RF filters, and so on.

2.1. Conventional Approach to reduce hardware complexity

Figure 1 shows conventional approaches to reduce hardware complexity on multi-service simultaneous reception by sharing a part of the analog processing part. Examples of receiver structures in order to sample the signals of multiple services by a single ADC are shown in Figures 1(a) and (b). Sharing the single ADC between multiple services reduces the number of ADCs required for multi-service simultaneous reception. Figure 1(c) shows an example of receiver structure for packet data transmission systems to realize multi-service simultaneous reception by a single antenna, RF unit, and ADC. Each technique is described as follows.

(a) FDM approach on IF band [4]

Received signals of communication services are converted from RF to intermediate frequency (IF) and multiplexed on IF band by selecting the center frequencies of respective signals converted to IF band appropriately without overlapping their frequency spectrums each other. The multiplexed signal is then sampled using a single ADC.

In this method, the IF signal multiplexed signals of multiple services can be transmitted through a single cable, then the number of coaxial cables can be reduced. Various communication services are treated efficiently by selecting the center frequencies of respective IF signals adaptively according to their bandwidths.

However there are some problems described as follows. Direct conversion technique is not so suitable for this method, because down converters from RF to IF are necessary. A certain large of bits and high sampling rate are necessary to the ADC. Computational load on digital filters becomes heavy to extract each signal of services from the IF signal.

(b) TDM approach according to bandwidth [3,5-7]

Input signal to the ADC is switched adaptively at high speed, according to the bandwidths of respective signals of multiple communication services. Thus the single ADC can samples all received signal in the time division manner. The sampling rate of the ADC is necessary to be high enough to satisfy sampling theorem in the all received signal.

Some modified and related techniques have been also investigated, such as sampling technique with variable sampling interval, synchronization technique under the condition of variable sampling interval, and so on.

(c) TDM approach for packet data transmission [8]

It is assumed that the center frequency and the bandwidth of the receiving signal can change in a wide range at the antenna and the RF unit. Packet data transmission systems are also assumed. Thus the received signal is that of only one communication service at a time, but it can be switched between communication services. The switching between communication services is performed according to the packet data transmission timing.

In order to maximize throughput, some techniques are necessary, such as collaborative packet scheduling.

3. PROPOSED RECEIVER STRUCTURE

As described in Section 2, sharing techniques are important to reduce hardware complexity in order to realize multi-service simultaneous reception efficiently. Previous investigations about sharing techniques however mainly dealt with DSP part, ADC, or IF signals. There are not so many investigations about the configurations of receivers

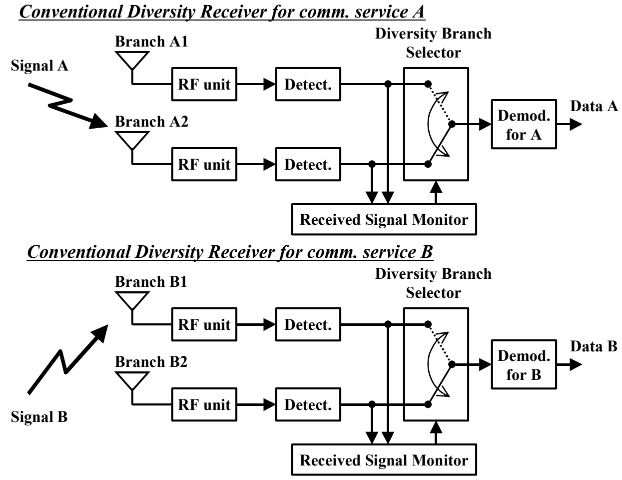


Fig. 2: Simultaneous reception by conventional diversity receivers (M=2, N=2, N_t=4).

for multi-service simultaneous reception to share antennas or RF units efficiently.

In mobile communication systems, on the other hand, diversity reception techniques are often utilized to overcome the influence of a time-varying channel, that is a fading channel, caused by multipath propagation environment. In diversity reception techniques, several received signals are usually obtained by several antennas, which are called diversity branches. Then, one received signal is selected from the obtained received signals, or the obtained received signals are weighted and combined into a new received signal appropriately, according to the received signal strength information (RSSI), resulting in compensate the influence of the time-varying channel.

Therefore, the diversity gain becomes higher with the increase in the number of diversity branches, whereas the hardware complexity of the receiver becomes also higher. Thus preparing many diversity branches is difficult, so the number of branches is usually from two to four.

Figure 2 illustrates an example of conventional diversity receivers for multi-service simultaneous reception. In Figure 2, selection diversity reception is assumed. The number of diversity branches for one communication service N is two, and the number of communication services for simultaneous reception M is two. The total number of diversity branches N_t is four, because two diversity receivers are necessary for two-service simultaneous reception. Thus, in multi-service simultaneous reception using conventional diversity receivers, the total hardware complexity becomes increased in proportion to N_t $(=NM)$.

Here, we consider the operation of diversity branches. In selection diversity reception, a single diversity branch is used to demodulate received signal in a certain moment. Thus, the other diversity branches do not perform at that moment. In maximal ratio combining diversity reception, the diversity branch whose received signal is weak does not contribute so much to the performance in a certain moment. Therefore, redundant diversity branches exist, and sharing the redundant diversity branches can decrease the hardware complexity.

We propose a concept of new receiver structure for simultaneous reception sharing diversity branches between communication services. Figure 3 illustrates an example of the structure of the proposed multi-service simultaneous receiver with diversity reception techniques. It is assumed that antennas and RF units composing diversity branches have wide capability and receive any signal that is one of the communication services. Therefore, each diversity branch changes the receiving services dynamically from one to another one according to channel states, and each communication service to receive is always selected by at least one branch to realize multi-service simultaneous reception.

In Figure 3, the total number of diversity branches N_t is three, and the number of communication services for simultaneous reception M is two. Then, the number of diversity branches per communication service N becomes 1.5. Thus the hardware complexity of the proposed receiver is lower than that of the conventional receivers illustrated in Figure 2.

Then, we consider the performance of diversity reception in the proposed receiver. The effective number of diversity branches for one communication service is expected to be one value from 1.5 to three, considering the operation of sharing diversity branches between the communication services. If the effective number of diversity branches becomes two or more, the performance of diversity reception in the proposed receiver is superior to that in the conventional receivers, namely the proposed receiver is expected to achieve both hardware complexity reduction and performance improvement.

In the proposed receiver, the effective number of diversity branches becomes increased because of sharing diversity branches between communication services receiving simultaneously. On the other hand, a diversity branch receiving the signal of one communication service is unable to be used for receiving that of other communication services simultaneously. When the optimum diversity branch for one communication service and another communication service is the same, all communication service can not always select the optimum diversity branch to receive the signal.

Therefore, the algorithm to select combinations of a diversity branch and a receiving communication service is a very important problem in the proposed receiver.

4. ALGORITHM TO SELECT COMBINATIONS OF DIVERSITY BRANCH AND SERVICE

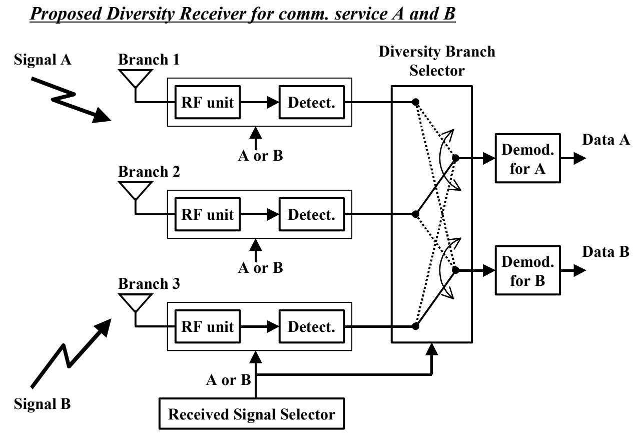


Fig. 3: Structure of proposed diversity receiver for simultaneous reception (M=2, N_t=3).

In the proposed receiver, a collision between the optimum diversity branches of respective communication services sometimes occurs because of sharing diversity branches between them. We assume here that received signal strengths of communication services to receive simultaneously are always known at all diversity branches in order to simplify the basic consideration. Then, we consider a procedure to select combinations of a diversity branch and a receiving communication service based on the received signal strength.

Our basic policy to select the combinations is described as follows.

(1) Each communication service is received by any one of diversity branches, namely, selection diversity is assumed.

(2) Each communication service can select the optimum diversity branch when a collision between the optimum diversity branches does not occur.

(3) The communication service, whose signal strength of the second optimum diversity branch is the weakest among communication services, can select the optimum diversity branch when a collision between the optimum diversity branches occurs.

We propose an algorithm based on the above description to select combinations of a diversity branch and a receiving communication service. Figure 4 shows a flowchart of the algorithm. A procedure of the algorithm is described as follows.

(i) Initialization: Define the sets of communication services and diversity branches.

$S=\{s_1, s_2, ..., s_M\}$: A set of communication services

$B=\{b_1, b_2, ..., b_{Nt}\}$: A set of diversity branches

(ii) Search optimum diversity branches for respective communication services from within the sets S and B.

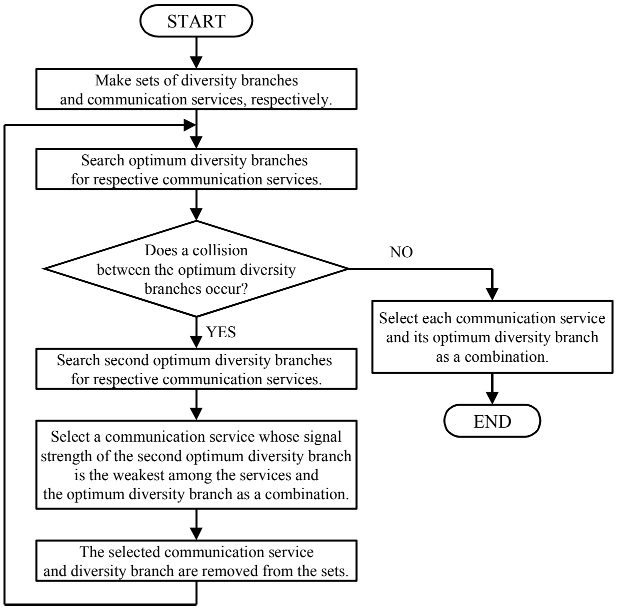


Fig. 4: Flowchart of Algorithm to Select Combinations of Diversity Branch and Communication Service.

(iii) Does a collision between the optimum diversity branches occur?

Yes: go next

No: go to (viii)

(iv) Search second optimum diversity branches for respective communication services from within the sets S and B.

(v) Select a communication service whose signal strength of the second optimum diversity branch is the weakest among communication services. Then, select the communication service and the optimum diversity branch of the selected communication service as a combination.

(vi) The communication service and the diversity branch, which have been already selected as a combination, are removed from the sets S and B, respectively.

(vii) Go to (ii)

(viii) Each communication service and its optimum diversity branch are selected as a combination.

(ix) End of procedure.

This algorithm can be performed, when the number of communication services and the number of diversity branches are large and then a chain collision occurs.

5. SIMULATION RESULTS

The performance of the proposed multi-service simultaneous receiver sharing diversity branches is evaluated by simulation. The simulation parameters are described in Table 1. All modulation types of communication services are the same QPSK to evaluate the basic characteristics of the diversity reception. It is assumed that all communication services has the same symbol rate and are synchronized between the services, to simplify the simulation. It is also assumed that the frequency offset is zero, the symbol synchronization and the phase tracking are perfect, and the combinations of a diversity branch and a communication service are selected every symbol based on the algorithm in Section 4, in order to evaluate the ideal performance. The whole hardware complexity of receivers is here evaluated by the total number of branches N_t.

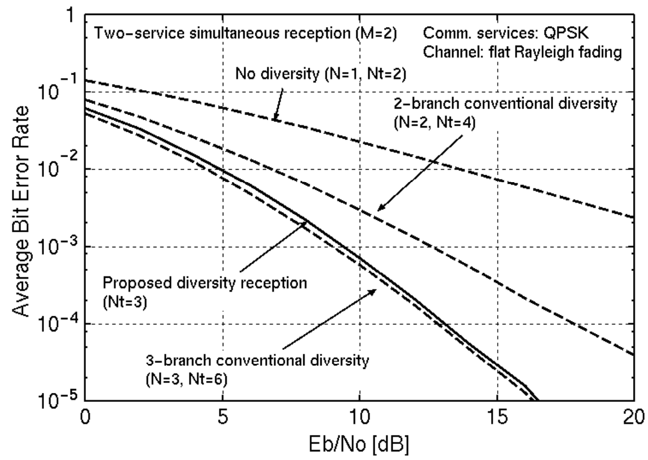


Fig. 5: BER performance versus Eb/No for M=2.

Figure 5 shows the bit error rate (BER) performance versus E_b/N_0 for M=2 (two-service simultaneous reception). The solid line represents the result of the proposed receiver for N_t=3. The dashed lines represent the results of the conventional diversity receivers with the number of diversity branches as a parameter.

As seen from Figure 5, the performance of the proposed receiver with N_t=3 is superior to that of the conventional receiver with N_t=4 in spite of smaller N_t, and is little degraded compared with that of the conventional receiver with N_t=6. Therefore, the effective number of diversity branches per communication service is close to three in the proposed receiver.

Figure 6 shows the required E_b/N_0 that can be achievable BER=10^{-2} versus the number of diversity branches per communication service N with the number of simultaneous reception M as a parameter. The solid and dashed lines represent the results of the proposed receiver

Table 1: Simulation parameters.

Modulation type (all services)	QPSK
Channel model	slow flat fading
Number of services for simultaneous reception M	from 1 to 3
Number of diversity branches N_t	from 1 to 6

with M=2 and 3, respectively. The dash-dotted line represents the result of the conventional diversity receiver, equivalent to M=1.

As seen from Figure 6, the required E_b/N_0 decreases with the increase of the number of diversity branches due to diversity gain. The required E_b/N_0 of the proposed receiver is smaller than that of the conventional diversity receiver under the condition of the same number of diversity branches per communication service, because of the gain by sharing diversity branches.

Figure 7 shows the effective number of diversity branches versus the total number of branches with the number of simultaneous reception M as a parameter. In the conventional diversity receiver (M=1), the effective and total number of diversity branches are the same. In the proposed receiver, the effective number of diversity branches decreases with the increase in M under the condition of the same total number of diversity branches. However the degradation of the effective number of diversity branches is approximately 0.3 for every increment of M.

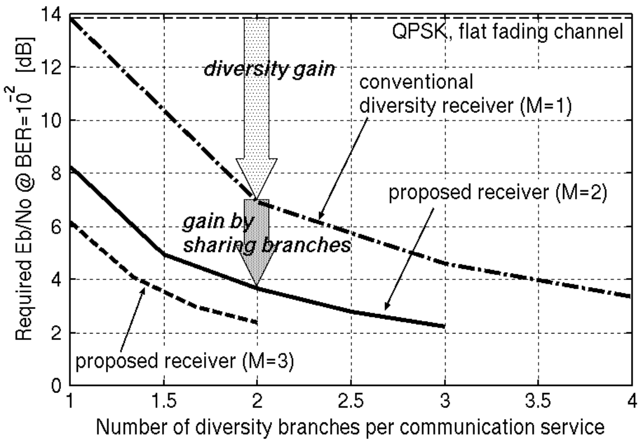


Fig. 6: Required E_b/N_0 versus the number of diversity branches per communication service.

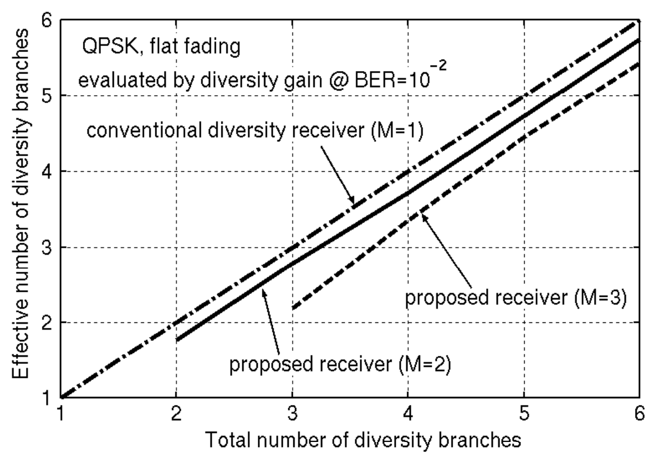


Fig. 7: Effective number of diversity branches per communication service versus total number of diversity branches.

6. CONCLUSIONS

We proposed a concept of a new receiver structure sharing diversity branches for multi-service simultaneous reception. In the proposed receiver, the hardware complexity was reduced by the decrease in the total number of diversity branches, and the performance was improved by the increase in the effective number of diversity branches by sharing diversity branches between communication services.

We gave a basic algorithm that selects combinations of a diversity branch and a communication service in order to avoid a collision of the optimum diversity branches for respective communication services.

As a result of the performance evaluation, it was confirmed that the proposed receiver based on the algorithm achieved both hardware complexity reduction and performance improvement.

Considering more practical algorithm to select combinations a diversity branch and a communication service is a future study.

REFERENCES

[1] H. Harada, "A Proposal of Multi-mode & Multi-service Software Radio Communication Systems for Future Intelligent Telecommunication Systems," *Proc. of Inter-national Symposium on Wireless Personal Multimedia Communications (WPMC99)*, pp.301-304, Sep. 1999.

[2] H. Harada, Y. Kamio, and M. Fujise, "Multimode Software Radio System by Parameter Controlled and Telecommunication Component Block Embedded Digital Signal Processing Hardware," *IEICE Trans. on Communications*, vol.E83-B, no.6, pp.1217-1228, June 2000.

[3] H. Harada, and R. Prasad, *Simulation and Software Radio for Mobile Communications*, Artech House Publishers, Boston, London, 2002.

[4] K. Sanda, N. Itoh, N. Suzuki, and K. Ito, "Multi-service Receiver for Automobiles," R&D Review of Toyota CRDL, vol.38, no.4, pp.35-42, Dec. 2003.

[5] R. Sawai, H. Harada, H. Shirai, and M. Fujise, "Adaptive Symbol Timing Synchronization Method Based on Maximum Likelihood Estimation for the Realization of Multi-mode & Multi-service Software Radio," *Proc. of IEEE Vehicular Technology Conference (VTC2000-spring)*, vol.2, pp.1276-1280, June 2000.

[6] R. Sawai, H. Harada, H. Shirai, and M. Fujise, "An Adaptive Symbol Timing Synchronization Method Multi-mode & Multi-service Software Radio Communication System," *IEICE Trans. on Communications*, vol.E84-B, no.7, pp.1885-896, July 2001.

[7] R. Sawai, H. Harada, H. Shirai, and M. Fujise, "A Feasibility of an Adaptive Sampling Processing Method for Software Defined Radio," *Proc. of IEEE Vehicular Technology Conference (VTC2001-spring)*, May 2001.

[8] "Common and Sharable Features of Standards," IST-2001-32125 FLOWS, Deliverable Number: D11, June 2003.

