# Development of software modem for the MBC experiment in Antarctica

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**Abstract:** In this paper, we describe a software modem for MBC (Meteor Burst Communication) developed by the authors. By using the software modem with newly developed demodulation techniques, RANDOM (RAdio Network for Data Over Meteor) system, an MBC system designed and developed by the authors, succeeds in shortening the length of packet header. In an experiment conducted in Antarctica in 2004, RANDOM system showed greatly improved performance compared to a commercial MBC system operated on the same link in 2002.

**Keywords:** Software modem, Meteor burst communications, Digital signal processor, Antarctica, RANDOM system

## Introduction

Billions of tiny particles from space enter the earth's atmosphere daily. As such meteor particles enter the earth's atmosphere, they collide with air molecules thereby forming ionized trails (so-called meteor bursts) capable of reflecting radio waves in the low VHF band. BLOS (Beyond Line of Sight) communication using meteor bursts is called MBC (Meteor Burst Communication). MBC is known to have several advantages over other BLOS communications such as satellite and HF communications [1][2]. At high latitudes, in particular, MBC has a strong advantage over HF communications since it is less subject to anomalous absorption events ( such as polar cap and aurora absorption)[3] [4].

During the period from 2002 to 2004, the authors conducted a series of MBC data transmission experiments in Antarctica. In those experiments, a master station at Syowa Station (Japan) collected data packets from a remote station at Zhongshan Station (China) 1430 km apart. Only in 2003, we added another remote station at Dome Fiji Station (Japan) 920 km apart from Syowa Station and tried to collect data packets from the two remotes simultaneously. Figure 1 shows the location of the Stations. For the first two years, the experiment was performed using commercial equipment manufactured by MCC (Meteor Communications Co.). In the last year, we replaced the system with RANDOM (RAdio Network for Data Over Meteor) system designed and developed by the authors. By using software modems with newly developed demodulation techniques [5], RANDOM system showed greatly improved performance. Detailed descriptions of our MBC experiments in Antarctica are found in [6]-[9]

In this paper, we describe the demodulation techniques used in the software modem and show some results of the experiment with RANDOM system in Antarctica comparing with the performance of MCC system.

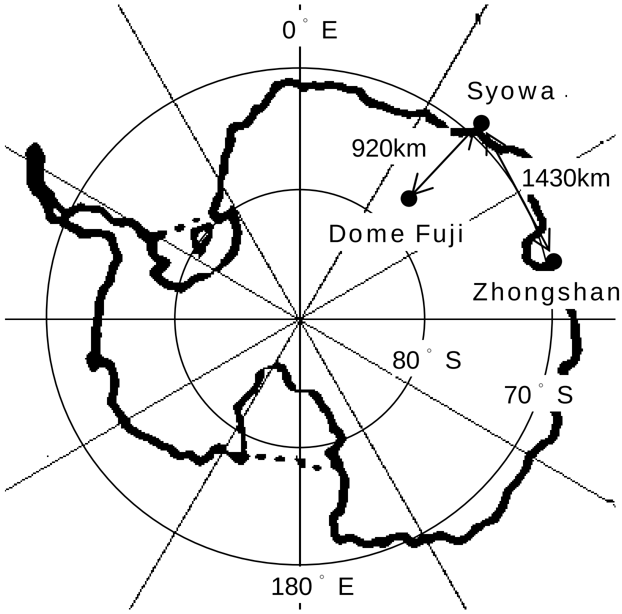

**Figure1:** Location of the Stations

## MBC BASIC protocol

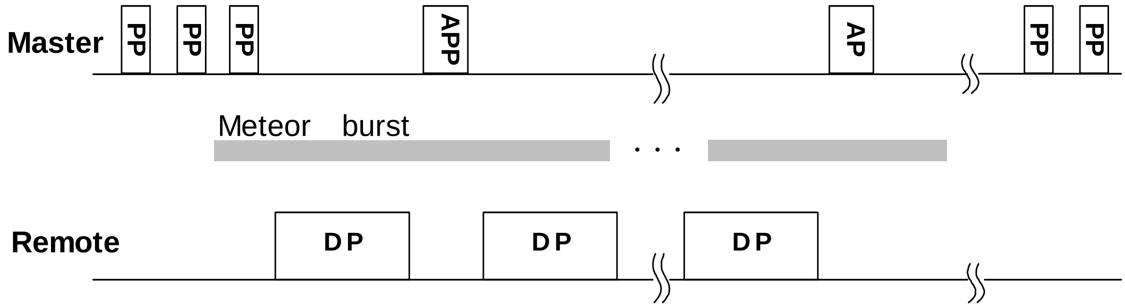

**Figure2:** Example of packet transmissions with MBC BASIC protocol

MBC BASIC is a simple protocol for MBC employed by RANDOM system in the experiment conducted in Antarctica in 2004. The protocol assumes a star network consisting of one master station and many remote stations. Figure 2 illustrates an example of packet transmissions between the master station and one of the remote stations. Communications are performed in half-duplex mode (i.e., the master station and all the remote stations use the same carrier frequency for their packet transmissions). The master station periodically sends probe packets (PPs). PPs can be received by a remote station if there is a meteor burst path between them. The remote station which has received a PP sends a data packet (DP) to the master station. If the master station successfully receives the DP, then it sends an acknowledge packet with probe (APP) or without probe (AP) to the remote station. An APP is sent when the master station can receive another DP. Otherwise, it sends an AP (e.g., in the case when the buffer for received DP is full). The remote station which has received the APP or AP removes the transmitted data set from the transmission buffer and proceeds to the next data set i.e., it sends the next DP immediately (in case of APP reception) or waits until the next PP reception for the next DP transmission (in case of AP reception). When the master station succeeds in receiving the header part of a DP but detects some errors in the data part, it sends a negative acknowledge packet (NP). The remote station which has received the NP retransmits the same DP.

## Structure of packets

| | | | | |
|---|---|---|---|---|
| PR(2) | Start Code (8) | PacketType(4) Master ID(4) | | PO(2) |

**Figure 3:** Common structure of all packets
(figures in parenthesis represent length in bits).

Figure 3 shows structure common to all packets used in MBC BASIC protocol. A packet starts with preamble bits <11> followed by a start code <10101010>. Regardless of modulation type of the following part, those bits are always BPSK (Binary Phase Shift Keying) modulated. The preamble bits and first three bits of the start code form a Barker code <11101>. This code is used for initial packet detection. The start code is also used for packet detection in a different way, symbol synchronization, and initial carrier phase estimation. The next byte specifies packet type and master ID. A packet ends with postamble bits, which repeats the last symbol twice.

| | | | |
|---|---|---|---|
| PR(2) | Start Code (8) | PacketType(4) MasterID(4) | PO(2) |

(a) PP format

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PR(2) | Start Code (8) | Packet Type(4) MasterID(4) | RemoteID (8) | SerialNo (3) DataLen (5) | CRC (8) | Data | CRC (16) | PO(2) |

(b) DP format

| | | | | | | |
|---|---|---|---|---|---|---|
| PR(2) | Start Code (8) | PacketType(4) MasterID(4) | RemoteID (8) | SerialNo (3) DataLen (5) | CRC (8) | PO(2) |

(c) AP, APP, and NP formats

**Figure.4:** Packet formats (figures in parenthesis represent length in bits).

Figure 4 describes structure of each packet. PP consists of only the elemental bits described above. Thus, the length of a PP is only 2.5 bytes.

Figure 4(b) shows DP format. RemoteID is an 8bit code designating the remote station from which the packet is sent. SerialNo is a packet serial number, which is increased by one with modulo 8 at each DP transmission. This number is used for detecting multiple receptions. DataLen indicates the length in bytes of the data part including CRC16. The maximum data length is 31 bytes. CRC8 is an 8 bit parity check sequence detecting errors in the header part. Similarly, CRC16 is a 16 bit parity check sequence detecting errors in the data part. Besides the data to be transmitted, the data part contains a data header which carries information concerning the data, such as data type, data serial number and the time when the data was acquired. The length of a data header is 5 bytes.

APP, AP, and NP have the same structure (Figure 4(c)). It is also the same with the header part of DP format with DataLen equal to 0. Thus, their length is 5 bytes.

## Software modem

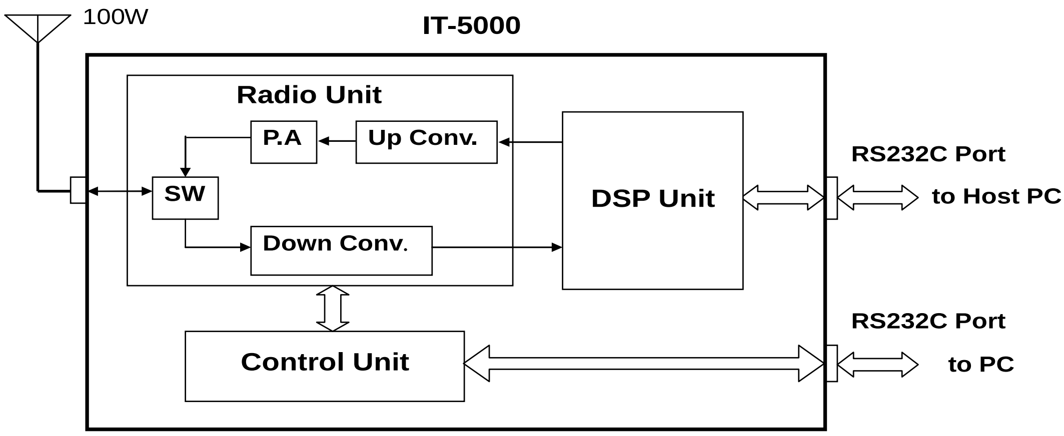


**Figure 5:** Block diagram of IT-5000.

Radio equipment specially designed for RANDOM system is named IT-5000. Figure 5 shows the hardware of IT-5000, consisting of radio, control, and DSP (Digital Signal Processor) units. The radio unit is responsible for 1) frequency conversion between low VHF and low IF (0.3~9.0 kHz) bands, 2) RF filtering and amplification, and 3) high speed switching between receiving and transmitting modes. The control unit monitors the radio unit. In case of detecting anomalous operation, it stops the radio unit and stores the error information to send a report to a PC (Personal Computer) when it is connected. The software, downloaded from a host PC into the DSP before each operation, provides all other functions needed as an MBC equipment, such as 1) packet detection, 2) carrier and bit synchronization, 3)modulation and demodulation in low IF band, 4) coding and decoding, 5) protocol handling, 6) interfacing between modem and host computer, and so on.

Since almost all communication functions are accomplished by software, IT-5000 can be applied to various communication systems by changing the software on the DSP. The software developed for the experiment in Antarctica is named SMR2003. It can treat BPSK and QPSK (Quadrature Phase Shift Keying) modulated packets with symbol speed of less than 2400baud. The transmission protocol used in SMR2003 is MBC BASIC. SMR2003 can detect and coherently demodulate short packets using new methods described below.

## Packet detection and bit synchronization

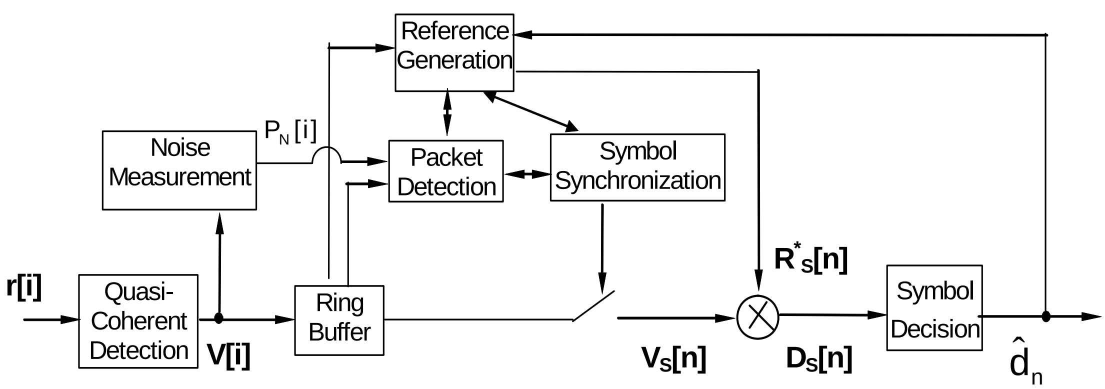

**Figure 6:** Diagram of the demodulation procedure.

Figure 6 diagrams demodulation procedure used in SMR2003. Input signal to the demodulator is a digitized waveform r[i] representing the ith sample of received low IF signal. We can express the waveform as

$$r[i] = \sqrt{2Ps}RE[g(i\Delta t)\exp\{j(\omega_c i\Delta t + \theta)\}] + n(i\Delta t) \quad (1)$$

where $Ps$, $\omega_c$, $\Delta t$, $\theta$, and $n(\,)$ represent received signal power, carrier angle frequency, sampling period, initial phase, and received noise, respectively. RE[ ] stands for taking the real part. The baseband transmission signal $g(t)$ is expressed by

$$g(t) = \sum_k p(t - kT_b)\, d_k \quad (2)$$

where $p(\,)$, $Tb$, and $d_k$ represent baseband transmission pulse, symbol duration, and kth complex symbol, respectively. In RANDOM system, we used a band limited baseband pulse that can be approximated by a rectangular pulse. Thus,

$$g[i] = g(i\Delta t) = d_k \quad \text{for } (k-1)T_b \le i\Delta t < kT_b \quad (3)$$

where $d_k = \pm 1$ for BPSK and $d_k = 1/\sqrt{2}(\pm 1 \pm j)$ for QPSK.

Quasi-coherent detection, in which received signal is first multiplied by cosine and sine waves having nearly the same frequency with the carrier frequency but an arbitrary initial phase and then the results for $K_b (= T_b / \Delta t)$ samples are summed (note that this operation corresponds matched filtering), yields a complex baseband signal

$$V[i] = \sum_{k=i-K_b+1}^{i} r[k]\exp(j\omega_c' k\Delta t) \quad (4)$$

where $\omega_c' \cong \omega_c$. Then, V[i] is stored in a ring buffer for the following operations. Since preamble and start code are fixed and BPSK modulated, we know the first $N_S$(=10) symbols of a packet, i.e., $d_k = (1,1,1,-1,1,-1,1,-1,1-1,\cdots)$. Packet detection and symbol synchronization are accomplished by detecting the symbols using the following hypothesis test for each sample.

[Hypothesis] The packet starts at the $(i - K_b N_s)$ th sample where i is the current sample time.

The test is performed as follows.

1) Calculate $B[i] = \left|\sum_{k=1}^{5} V[i-(N_s-k)K_b]*d_k\right|^2$. If it is less than a threshold (e.g., $2.2\cdot P_N[i]$ was used in the experiment in Antarctica, where $P_n$[i] stands for measured current noise power), discard the hypothesis.

2) Calculate B[i]-B[i-1]. If it is less than a threshold (e.g., $2\cdot B[i-1]$ was used in the experiment in Antarctica), discard the hypothesis.

3) Calculate $R[i] = \sum_{k=1}^{N_s} V[i-(N_s-k)K_b]*d_k$, which is referred to as a reference signal.

4) Obtain soft decisions $D[i,k] = \mathrm{Re}\{V[i-(N_s-k)K_b]R^*[i]/|R[i]|\}$ and hard decisions $\hat{d}_{i,k} = \mathrm{sgn}\{D[i,k]\}$ for k=2,3,...,$N_S$.

5) Compare $\hat{d}_{i,k}$ with $d_k$ for k=2,3,...,$N_S$. If $\hat{d}_{i,k} \neq d_k$, discard the hypothesis.

6) Calculate $C[i] = \sum_{k=2}^{N_s} D[i,k] * d_k$. If $|C[i]|^2$ is less than a threshold (e.g., $2 \cdot P_N[i]$ for PP detection and $1.5 \cdot P_N[i]$ for other packet detections were used as the threshold in the experiment in Antarctica), discard the hypothesis.

7) Hold $C[i]$ and Compare it with $C[i+j]$ for j=1,2,...,$K_b$-1, which will be obtained later. If $C[i] < C[i+j]$, discard the hypothesis.

If the hypothesis for $i = i_b$ passed all the tests, then we decide that a packet is arrived and its symbol timing is $i = i_b + nK_b$. We adopt fixed timing method for the symbol synchronization, i.e., the symbol timing is not updated for a packet reception since RANDOM system uses short packets only.

## Carrier synchronization

As is shown in Figure 6, PSK demodulation in SMR2003 is accomplished by multiplying $V[i_b + nK_b]$ with $R^*[i_b + nK_b]$, complex conjugate of the reference signal. Thus, carrier synchronization in SMR2003 is nothing but a generation of the reference signal. Since $\omega'$ is not exactly equal to $\omega$, the reference signal needs to be renewed symbol by symbol. In SMR2003, we thus employed the following recursive procedure to generate the reference signal at each symbol.

$$R_S^*[n] = (1-\alpha)V_S^*[n-1] \cdot \hat{d}_{n-1} + \alpha R_S^*[n-1] \qquad (5)$$

where

$R_S[n] = R[i_b + nK_b]$, $V_S[n] = V[i_b + nK_b]$, and $0 \leq \alpha \leq 1$.

The reference signal previously obtained for the packet detection can be used as the initial value. Note that the recursive equation (5) is equivalent to

$$R_S^*[n] = (1-\alpha)\sum_{k=1} \alpha^{k-1} V_S^*[n-k] \cdot \hat{d}_{n-k} \qquad (6)$$

which represents a sum of $V_S^*[n-k] \cdot \hat{d}_{n-k}$ weighted by $\alpha^{k-1}$, so that we refer to the operation as weighted decision feedback method.

The estimated carrier phase is expressed by

$$\hat{\theta} = \arg R_S[n] = \tan^{-1}\{IM(R_S[n]) / RE(R_S[n])\}. \qquad (7)$$

Thus, assuming AWGN (Additive White Gaussian Noise) channel with one side noise power density $N_0$ and calculating squared averages for real and imaginary parts of the recursive equation (5), we can derive the following equation:

$$\mathrm{Var}(\hat{\theta}) = \frac{1-\alpha}{(1+\alpha) \cdot 2P_s T_s / N_0}$$

which represents the variance of the phase estimation error. For the case of $\omega_c = \omega_c'$, the larger the constant $\alpha$, the smaller the estimation error and thus the performance approaches ideal CPSK (Coherent PSK) demodulation. On the other hand, in the case of $\omega_c \neq \omega_c'$, a smaller $\alpha$ provides more sensitive phase tracking. In particular, $\alpha = 0$ corresponds to DPSK (Differential PSK) demodulation. We used $\alpha = 0.7$ in the experiment in Antarctica, which yields the performance almost the same as CPSK demodulation for the case of $\omega_c = \omega_c'$ and maintains relatively high performance even in the case of $\omega_c \neq \omega_c'$ .

## Description of the experiment in Antarctica

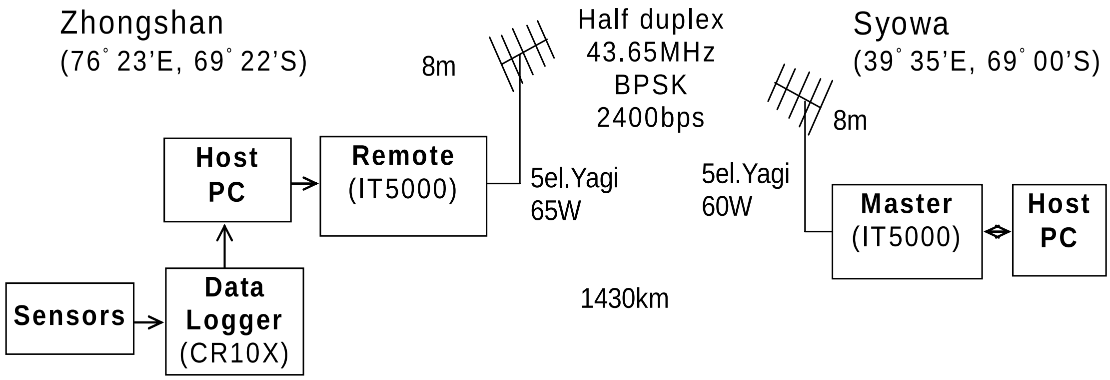


**Figure 7:** Configuration of the experiment with RANDOM system

Figure 7 shows configuration of the experiment with RANDOM system in Antarctica. The remote station at Zhongshan Station was set to acquire data of 20 bytes from a data logger (designated CR10X) with an interval of 5 minutes. It tries to transfer the data as a DP to the master station at Syowa Station according to MBC BASIC protocol. An acquired data set from the data logger is first stored in memory in a host PC. Then, the host PC sends the data set to a buffer in IT-5000 if there is room. The buffer in IT-5000 can accommodate 4 data sets. The memory size in the host PC was set to 100 data sets. Thus, the size of transmission buffer in the remote station was 104 data sets in all. If the buffer is full, newly acquired data will be lost. In the master station, the size of receiving buffer in IT-5000 is also 4 data sets. Thus, if the master station receives four DPs successively, then it will send AP instead of APP. DPs in the receiving buffer are transferred to a host PC when the master station is not busy i.e., after AP transmission or when it detects no packet arrival after APP transmission. The time required for sending the received data from IT-5000 to the host PC is about 1.6 seconds for each data set. Moreover, in order to evaluate the maximum data throughput, the remote station was set to send dummy data packets in the case of receiving a PP when it has no data to be transmitted. The system was operated only 5 minutes in each 10 minutes interval to avoid interference with another MBC experiment conducted during the same period.

Similar experiments with MCC system were performed in Antarctica in the previous years, i.e., the remote station at Zhongshan Station (and also the remote station at Dome Fuji Station for the experiment in 2003) generated 20 bytes data with an interval of 5 minutes and tried to transfer the data to the master station at Syowa Station according to a protocol similar to MBC BASIC protocol. However, the size of transmission buffer in the remote station was not specified in the experiment with MCC system. Instead, the lifetime of DPs was set to 2 hours. Since MCC system does not have function for dummy data transmission, the remote station without data to be transmitted did not send any packets even if it succeeded in receiving PPs. The MCC system was also set to operate only 5 minutes in each 10 minutes interval.

## Some results of the experiment

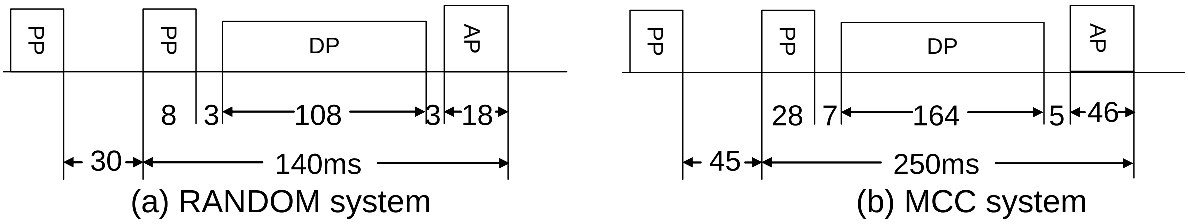


**Figure 8:** Required duration for a data transmission

Figure 8 shows timing diagram for a transmission of 20 bytes data set in RANDOM and MCC systems. Both the systems use BPSK modulation but bit rate is 2400 bps in RANDOM system and 4000 bps in MCC system. In spite of slower transmission speed, the duration of the channel opening required for a successful data transmission in RANDOM system is 140 ms, which is much shorter than 250ms in MCC system. It is known that typical average duration of meteor burst channels is a few tenths of a second and the number of meteor burst channels increases as the bit rate decreases. Thus, RANDOM system is expected to have greatly improved performance.

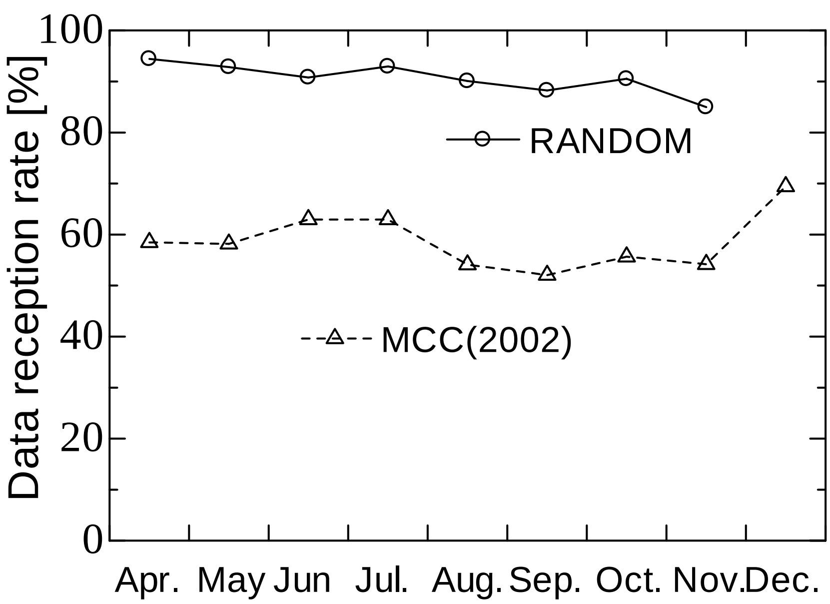


**Figure9:** Monthly averaged data reception rates

Figure 9 shows monthly averaged data reception ratios for the experiments with RANDOM and MCC systems. Here, data reception ratio is defined by the number of received data sets during a specified period divided by the number of data sets generated during that period. Dummy data packets are not included in the statistics. In both the experiments, we have set the remote station to generate 288 data sets per day. In the monthly averaging, we have excluded days listed in Table 1 because the systems stopped operation or operated under some different parameter settings in those days. We see from the figure that monthly data reception ratios of RANDOM system are almost always 90 % or higher. Note that this implies that RANDOM system has enough ability to collect almost all data from the remote station since the system in the experiment operates only half of each 10 minutes interval as was previously stated. On the other hand, the data reception ratio of MCC system averaged over whole period of the experiment is about 60%. That is, concerning the data reception ratio, the performance of RANDOM system is about 1.5 times higher than that of MCC system.

Some initial studies on the comparison about the data throughput are found in [8]. Further studies on the performance comparisons will be found in [10] and future papers.

Table 1: List of days excluded from the analysis.

| System(year) | Days excluded from the analysis |
|---|---|
| RANDOM(2004) | Oct.12,Oct18-20, Oct.22,Oct.29,Oct.31, Nov.21,Nov.29 |
| MCC(2002) | Apl.18, Apl.21-22, Jun.15-16, Aug.29-Sep.17, Oct.16-29,Dec.6-10, Dec.30-31 |

## Conclusions

In this paper, we described new demodulation techniques developed for a software modem used in RANDOM system. The software modem is a program running on a DSP. Input signal to the DSP is a sampled low IF signal and firstly stored in a ring buffer. Packet detection and symbol synchronization are accomplished by performing a hypothesis test for each sample taking from the ring buffer. A recursive equation corresponding to a weighted decision feedback method is used for carrier phase tracking. These techniques are suitable for the software modem since they are easily programmable. By using the new demodulation techniques, RANDOM system succeeded in shortening the length of packet header and thus reduced the duration of channel opening required for successful data transmission. Then, it was shown that, in case of transmitting 20 bytes data using MBC BASIC protocol, RANDOM system requires only 140 ms whereas MCC system requires 250 ms.

An MBC data transmission experiment using RANDOM system was conducted in Antarctica in 2004 and showed greatly improved performance compared to that of MCC system operated on the same link in 2002. Averaged data reception ratio in the experiment with RANDOM system is about 90% whereas that in the experiment with MCC system is about 60%. The performance improvement is the result of adopting the software modem with the newly developed demodulation techniques.

## Acknowledgments

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