Feasibility study of using FM radio for data transmission in a Vehicular Network

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Abstract—**This paper uses GNU Radio and USRP boards to implement a feasibility study of using FM radio for data transmission in vehicular networks. Specifically, it implemented packet transmission with GNU Radio, USRP boards and FM radio (88MHz~108MHz) and observed the packet loss rate, packet correct rate with different distances.**

Keywords- Cognitive radios; vehicular network; USRP; FM radio

I. INTRODUCTION

"In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access" [1]. According to the FCC, 1) A large amount of the licensed spectrum is used sporadically, with the temporal and geographical variations in the utilization ranging from 15% to 85%. 2) Complicated and old regulations prevent open and flexible access to the available spectrum. The apparent bottleneck of spectrum scarcity is thus not due to physical spectrum scarcity, but rather is based on inefficient spectrum allocation schemes and regulations. Therefore, in order to increase the efficiency of natural spectrum resource utilization, more flexible spectrum management techniques and regulations are required. Cognitive Radio is one such technologies that promises to achieve this goal.

Cognitive radio (CR) is a key technology that can enable flexible, efficient and reliable spectrum use by adapting the radio's operating characteristics to the real-time conditions of the environment [2]. In a Cognitive Radio Network (CRN), protection of primary users (PUs) or licensed users is the essential. The secondary users (SUs) or unlicensed users must monitor each primary user's usage patterns. This is because the SUs have lower priority, and so the detection of PUs usage is essential.

FM broadcasting uses frequency modulation (FM) to provide high-fidelity sound over broadcast radio. FM is commonly used at VHF radio frequencies for high-fidelity broadcasts of music and speech, and normal (analog) TV sound is also broadcast using this technology. A narrow band form of FM is used for voice communications in commercial and amateur radio settings, and around the world, the broadcast band falls within the VHF part of the radio spectrum, most often 87.5 to 108.0 MHz [3].

Vehicular networks (also known as VANETs) are a cornerstone of the envisioned Intelligent Transportation Systems (ITS). By enabling vehicles to communicate with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Roadside-to-Vehicle Communication (RVC), such networks will contribute to safer and more efficient roads by providing timely information to drivers and concerned authorities [4].

This paper thus undertakes some related preliminary work by conducting a feasibility study of using FM radio for data transmission in vehicular networks. Specifically, it focuses on used FM bands to transmit data between two USRP boards (also called the transmitter and receiver).

II. TESTBED SETUP

The following equipment is required in the testbed. With regard to hardware, we need two laptops, two USRP boards with one transmitter board and one receiver board [5]. For the software, we need to have Cygwin, the GNU Radio software development toolkit and the Python programming language. IN addition, in this setup the transmitter only can send, and receiver only can receive.

A. USRP

The Universal Software Radio Peripheral (USRP) is an openly designed low-price SDR hardware platform which implements radio front-end functionality and A/D and D/A conversion using the Universal Serial Bus (USB2) standard to connect to the PC that hosts the device. The current USRP device (Fig. 1) consists of a motherboard containing up to four high speed 12-bit 64 Msps analog to digital converters (ADC), and four high speed 14-bit 128 Msps digital to analog converters (DAC). RF front ends are attached in the form of daughter cards which can currently cover all the existing radio bands from 0 Hz to 5 GHz.

B. GNU Radio

GNU Radio is an open source toolkit for building software radios. It is designed to run on desktop computers and, combined with minimal hardware, allows the construction of simple software radios. The GNU Radio signal processing library provides signal processing blocks for modulation, demodulation, filtering, and IPO operations, such as file access. In addition, it also provides blocks for communicating with the USRP. New blocks can be added as needed. A radio is built by connecting these blocks to form a flowgraph, which is a directed acyclic graph in which the

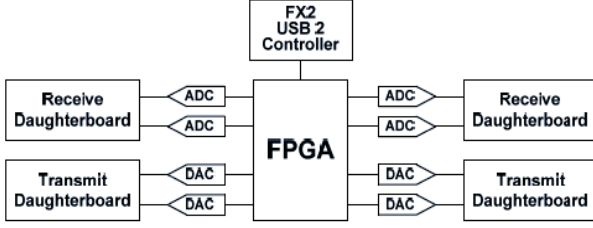vertices are the GNU Radio blocks and the edges correspond to data streams [6].

Fig. 1 Block Diagram of the USRP

C. TVRX vs. BasicTX

TVRX and BasicTX daughter boards were used in the system. The TVRX board was used to receive the signal, and the BasicTX board was used to transmit it.

III. METHODOLOGY

A number of problems arose in attempting to implement this system. First, with regard to the data transmission, the last packet is always false, and this will adversely affect the accuracy of the data. Furthermore, the data is divided into serial packets for delivery, and the last packet may not be filled up. Therefore, this paper uses junk data to complete any final packets that need to be filled. One related challenge is that the transmitter only can send, and the receiver only can receive, therefore this paper uses the packet header to solve this issue, as shown in TABLE I. The receiver can use the packet header information to divide the junk data and obtain the correct data.

TABLE I. TRANSMITTER PACKET HEADER:

1	2	3	4	5	6	7	8	9	10	11...............1500
Packet number	Packet size	Data size	Total packets	Last packet size	Payload

Second, in wireless networks and FM bands, the accuracy of the packets received by the base station will be affected by interference from other FM radio stations. This work thus uses an Agilent N9310A RF Signal Generator [7] to generate the FM signal, and the TVRX board to receive it. Fig. 2 shows if transmit data at radio station (primary user) situation and the USRP receiving limit was about -90dBM. In Fig. 3, when the BasicTX board transmits a signal at 97.1MHz, the signal can almost not be clearly received, due to original signal interference. This means that the signal we transmit needs to be stronger than that sent by the primary users or the noise. Specifically, in Fig. 3 we can see that the signal strength needs to be greater than the primary users' or noisy signal strength of 20dB, so that our system can correctly receive the packets without interference from the original signal.

The third problem is related to the distance between two machines. I will use the Free Space model and Two-ray Ground Reflection Model (H.T. Friis, 1946), to verify the distance with the receiver's receiving power, and then use

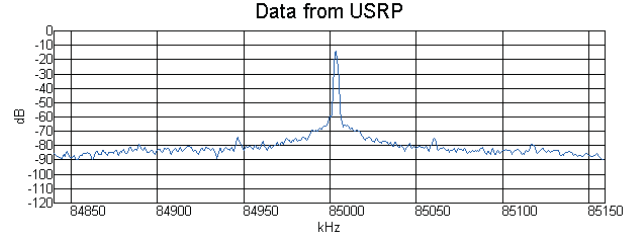this result to measure the distance and performance of packet correct rate [3].

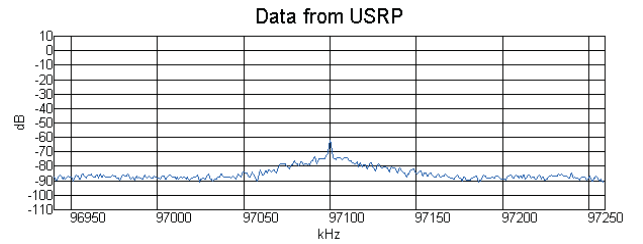Fig. 2 Using a Spectrum Analyzer machine to generate the FM signal

Fig. 3 Signal interference condition

Fig. 4 shows the implementation equipment, namely two laptops, two USRP boards, a BasicTX board, a TVRX board, and three boosters with a transmitter and receiver. As the level of gain is increased, it has been shown that a minimum signal of -105dBm is needed in order to produce the requisite 10dB of SNR [8]. Although the TVRX can support -105dBm receiver sensitivity, it needs to have enough antenna gain to transmit/receive the signal. However, in this work no antenna gain was used with the receiver, because it may lead to interference from the PU's signal. On the sender side, the booster gain was 30dBm (each), but we also need to consider line loss, converter loss and adapter loss. An RF Signal Generator was used to measure the converter signal, and the results are shown in Fig. 5. We can see that the converter loss was 20dB, 15dB and 11dB, and the coaxial cable adapter may cause 3~4dB line loss/adapter loss, due to connecting Booster_1, Booster_2, Booster_3 and also each adapter.
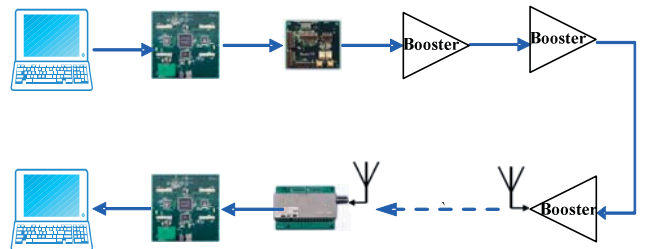

Fig. 4. Testbed implementation equipment

According to (1) and (2), when the distance between the transmitter and receiver is 20 m, the free space and two-ray ground path losses are -55.48 and -53.76 dBm (show in Fig. 6), when P_t is 0.05mW, G_t is 40dB(90dB-11dB-15dB-20dB-4dB), h_t is 5.8 m and h_r is 1 m.

$$P_r = \frac{P_t \cdot G_t \cdot G_r \cdot \lambda^2}{(4\pi d)^2 L} \tag{1}$$

$$P_r(d) = \frac{P_t \cdot G_t \cdot G_r \cdot h_t^2 \cdot h_r^2}{(d)^4 L} \tag{2}$$
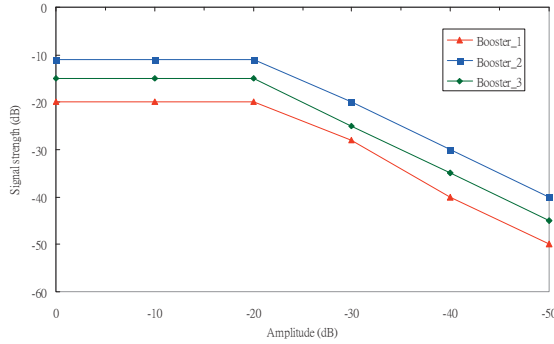

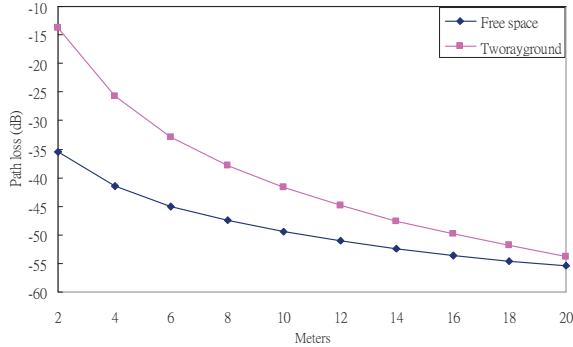Fig. 5 Measurement converter loss dependent on the Boosters

Fig. 6 Path loss dependent on distance

IV. IMPLEMENTATION AND RESULTS

This paper proposes a feasible data transmission process, and examines the effects of different distances and data rates on the performance. A very important consideration in data communications is how fast data can be sent, in bits per second, over a channel. The data rate depends on three factors: the bandwidth available, the level of the signal used, and the quality of the channel [9]. For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate, as shown in (4). L is the number of signal levels used to represent data, if L is just 2, the receiver can easily distinguish between a 0 and a 1. The normal FM bandwidth is 200 KHz, but in the Fig. 2 we can saw that the bandwidth sent in our system may only be 100K, and perhaps even less, as the transmission power is much lower than that of a radio station. The Nyquist bit rate formula provides the transmission rate limit, so in this work the bit rate limit is 200 KHz (L=2). In reality, a noiseless channel does not exist, therefore in this work the Shannon capacity is used to determine the theoretical highest data rate for a noisy channel, as shown in (4). In this formula, if the noise is so strong that the signal is faint, this means that the capacity of this channel is zero, regardless of the bandwidth. In other words, we cannot receive any data through this channel.

$$BitRate = 2 \times bandwidth \times \log_2 L \tag{3}$$

$$Capacity = bandwidth \times \log_2(1 + SNR) \tag{4}$$

This next section will undertake a performance feasibility study of using the FM radio band for data transmission in a Vehicular Network. Fig. 7 shows the results from the Handheld Spectrum Analyzer [10] used to measurement the signal strength on the receiver's side. It can be seen that the receiver almost receives no data from the transmission side when there is a weak signal (about -88dBm). It is thus assumed that the receiver sensitivity is -90dBm. The BasicTX board's transmitter power is 0.05mW (-13dBm), and the TVRX chip has 8~10dB Noise [11]. The total loss can be computed with the addition of 10 dB as the required SNR for a BPSK demodulation with a 10^{-3} error rate [12]. This yields

$$P_r - NF - SNR_{DBPSK} = -55.48 - 10 - 10$$
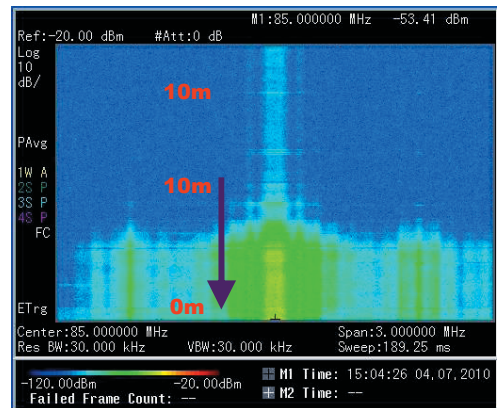$$= -75.48 dBm$$

Fig. 7. Handheld Spectrum Analyzer measurement receive signal strength

Computer with receiver sensitivity (-90dBm), still to differ about 15dB, I think that may cause interference with FM radio, If no the FM radio interference, maybe can reach 100m without packet loss. So, the further work I will do the spectrum hold detection to get low noise channel (no primary user). Like Fig. 8, measurement all the FM bands (88MHz~108MHz) signal strength, the radios have been spectrum hold, that I can reach better implementation.
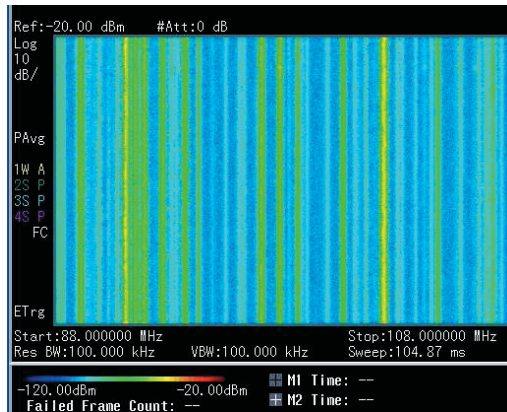

Fig. 8.   Handheld Spectrum Analyzer measurement of the FM radio signal strength

Different distances (1~20m) and different data rates (35Kbps, 125Kbps, 216Kbps) were measured. In USRP the minimum bit rate is 35Kbps and the maximum is 4000Kbps. However, the FM radio can not reach the maximum (according to (3) the maximum bit rate must be less than 200Kbps), otherwise USRP overrun will occur ("uO"), and the USRP samples will be dropped because they are not read in time [13], as shown in Fig. 9:
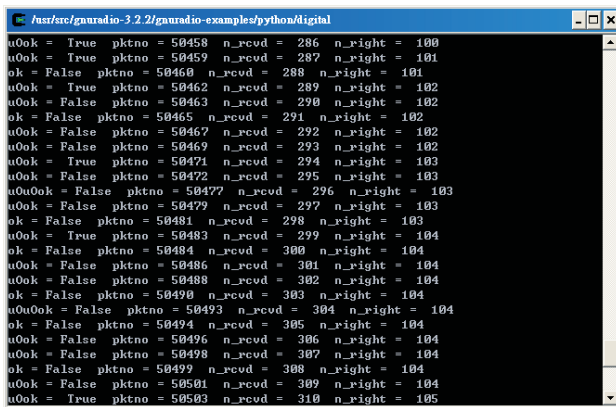

Fig. 9.   USRP overrun

In the implementation result, shown in Fig. 10 we can see that the low bit transmission rate can achieve a better rate of packet accuracy as the distance increases (i.e., the data rate and distance are inversely proportional). The stability is also higher, as the system has enough time to process the received data. A low bit transmission rate can reach longer distance than the higher bit transmission rate, as "all things being equal, a high data rate system will not transmit as far as a low data rate system, leading to trade-offs" [14].
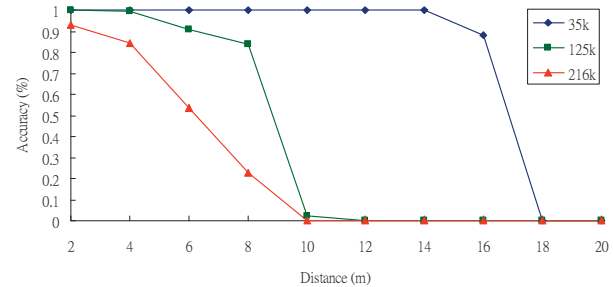

Fig. 10 Packet receive accuracy

The over-the-air data rate, the rate at which the radios communicate, is a component in determining the reception sensitivity of a radio, regardless of the type of spreading or modulation technique. For every doubling of the data rate, the reception sensitivity is reduced by 3 dB, as shown in Fig. 11 [14]. Fig. 12 shows the packet loss rate, demonstrating that the higher bit rate was unstable in the implementation. The transmission distance will decrease as the transmission rate rises [15], and a higher bit rate requires a higher SNR, at least to a first approximation. As the receiver is moved away from the transmitter, the total amount of energy that arrives at the receiver is initially dominated by the transmitted signal, but this is no longer true as it moves further away. Higher bit rates thus have a higher requirement for cleansignals.

Over-the-air data rate	Receive sensitivity
11 Mbps	82 dBm
5.5 Mbps	85 dBm
2 Mbps	89 dBm
1 Mbps	92 dBm

Fig. 11 Typical reception sensitivities vs. data rate for 802.11b radios

Fig. 12 Packet loss rate

Fig. 14 Number of packets received with a car at slowdown until stopping
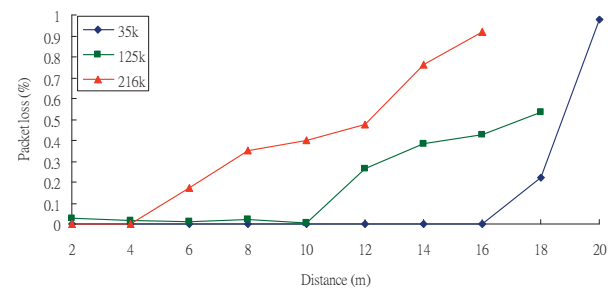(at one second)

In Vehicular Networks, a low bit rate may mean that the vehicles can not receive enough packets due to their mobility. For example, when the vehicle's speed is 60 km/h, the base station may only receive 2~3 packets within the base station range (16m/s). Further, with regard to the possibility of packet loss, receiving few packets is very risky with regard to performance. If we assume that a car's velocity is fixed at 60Km/h, the total number of packets received is shown in TABLE II. In this case, the 125Kbps bit rate achieves better results than 35Kbps. The implementation results are shown in Fig. 13, when the car velocity was constant. If we consider that a car will slow down because of traffic, the time in the radio range of the base station will become longer. The braking distance can calculate with (5), in which g is the acceleration of gravity ($9.8 m/s^2$, about 10), v is the average velocity (meter/s), and u is the friction coefficient ($\leqq 1$). Therefore, the weight will be greater if the distance is less than the braking distance. The braking time will be as shown in (6), and each one meter duration time will be calculated with (7). The implementation results are shown in Fig. 14, and these also reveal that a higher bit rate can receive more packets than a lower one.

$$
\begin{aligned}
&brake\_distance \\
&= average\_speed \times brake\_time \\
&= (v/2) \times v/(u \times g) \\
&= v \times v/(2 \times u \times g)
\end{aligned}
\tag{5}
$$

$$
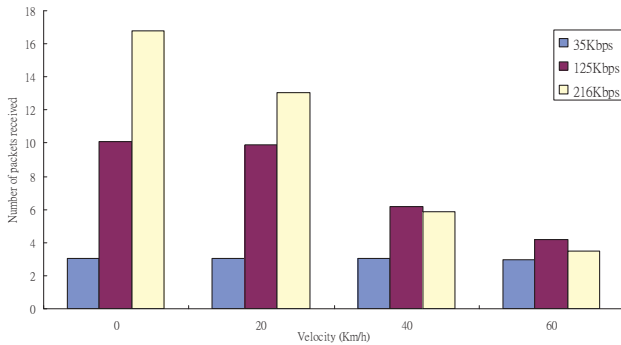dt = v/(u \times g)
\tag{6}
$$

$$
s = v_0 t - \frac{1}{2} a t^2
\tag{7}
$$

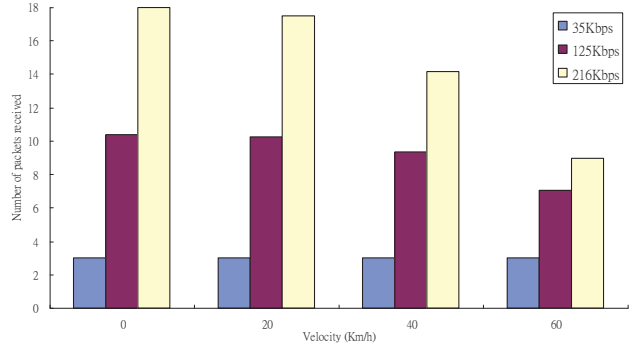Fig. 13 Number of packets received with a car at constant velocity
(at one second)

V. CONCLUSIONS AND FUTURE WORK

In short, the results of this study show that a low bit rate can reach better implementation curves and also have more stability, but also have greater transmission time. In Vehicular Networks, the low bit rate is not suitable for objects that high mobility, but a high bit rate may cause significant packet loss. The bit rate depends on the equipment used and the environment. In future work, I will consider utilizing energy detection to examine the channel condition. Energy detection can detect spectrum hold and use a low noise channel or one without a primary user to transmit data without interference. With no interference, the data received accuracy and transmission range should be better than those achieved now.

REFERENCES

[1] Carlos Cordeiro, Kiran Challapali, and Monisha Ghosh. "Cognitive PHY and MAC layers for dynamic spectrum access and sharing of TV bands." ACM TAPAS, Aug. 2006.

[2] Liang Hu, Villy B. Iversen, and Lars Dittmann, "Survey of PHY and LINK layer functions of cognitive radio networks for opportunistic spectrum sharing," Communications in Computer and Information Science, Vol.26, pages 10–24. 2009.

[3] FM broadcasting, http://en.wikipedia.org/wiki/ FM_broadcasting

[4] http://ivc.epfl.ch/

[5] Omer Mian, Ruolin Zhou, Xue Li, Seng Hong, and Zhiqiang Wu, "A Software-defined radio based cognitive radio demonstration over fm band international conference on wireless communications and mobile computing," pages 495-499, June 2009.

[6] Rahul Dhar, Gesly George, Amit Malani, and Peter Steenkiste, "Supporting integrated MAC and PHY software development for the USRP SDR," Networking Technologies for Software Defined Radio Networks, pages 68-77, Sept 2006

[7] Agilent N9310A RF Signal Generator User's Guide, http://www.rselectronics.com/Attachments/PDF/Agilent_N9310A.pdf

[8] Aadil Volkwin, "Suitability of a commercial software defined radio system for passive coherent location", Cape Town, May 2008

[9] Forouzan, "Data Communications and Networking", fourth edition, McGraw-Hill International Edition, 2007.

[10] Agilent N9340B Handheld Spectrum Analyzer, http://www.rselectronics.com/Attachments/PDF/Agilent_N9340B.pdf

[11] 4937 DI5 RF Tuner Module 3x8899 (3x7702) Advance Data Sheet, MICROTUNETM, September 2001

[12] David Ruffieux, "A 1.2-mW RDS receiver for portable applications", SOLID-STATE CIRCUITS, vol. 39, no. 7, July 2004.

[13] Firas Abbas Hamza, "The USRP under 1.5X Magnifying Lens", Rev 1.0, Jun 2008.

[14] Tim Cutler, "Speed vs. Distance", http://www.isa.org/InTechTemplate.cfm?Section=article_index1&template=/ContentManagement/ContentDisplay.cfm&ContentID=21286, November 2002

[15] Pasquale Romano, "The range vs. rate dilemma of WLANs," http://www.commsdesign.com/design_corner/showArticle.jhtml?articleID=17301701, 2004.

[16] Ta-Yin Hu、Tzu-Hsiang Su ，"Impact of traffic characteristics on inter-vehicle communications"，National Cheng Kung University, Dept. of Institute of Telecommunications Management, 2008.

TABLE II.   THE NUMBER OF PACKETS THE RECEIVER WILL RECEIVE

Bit rate	Packet /s	Interval (ms)	Average packet loss rate	Average Receiving packet/s	Average accuracy	Average Receiving _complete packet/s	Distance
35Kbps	3.0	333.3	0.024	3.0	0.98	2.956178	2-16m
125Kbps	10.4	96.2	0.187	8.9	0.47	4.186318	2-16m
216Kbps	18.0	55.6	0.343	11.0	0.31	3.50084	2-16m