Millimeter Wave Behavior Recognition Platform

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Abstract

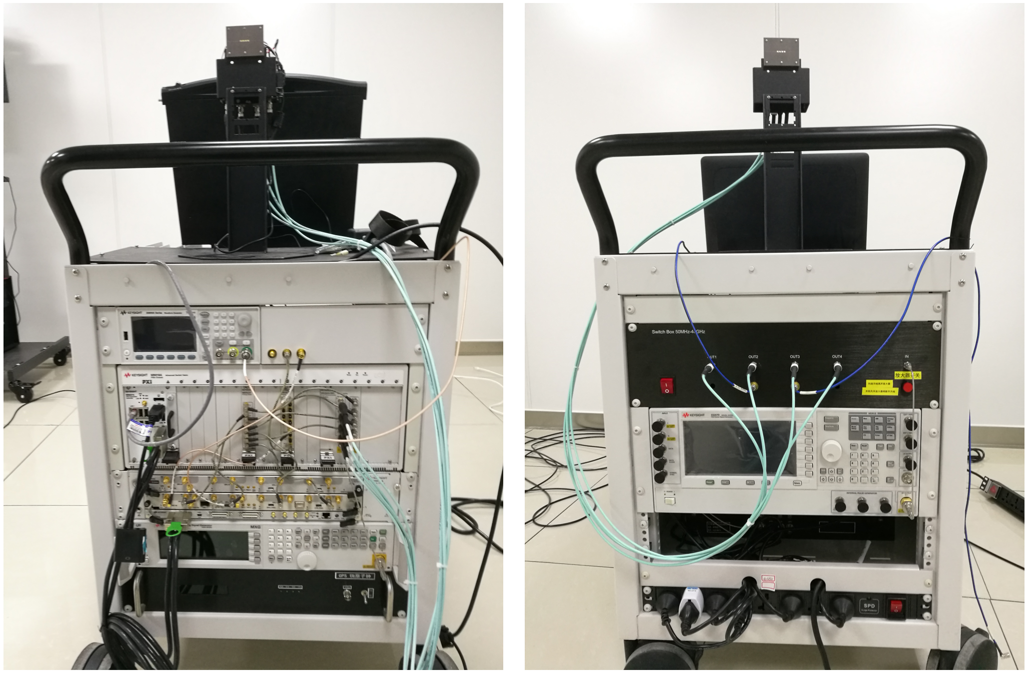
Radio-based behavior recognition is an active research area. However most current works focus on frequency band below 6G due to the limitation of hardware platform. In this paper, we take the advantage of the various equipments of our school and build a millimeter wave behavior recognition platform. We modify the off-the-shelf millimeter wave channel sounding equipment and implement the corresponding physical layer algorithms. We can obtain the channel state information (CSI) for future research via our platform. To verify the accurate of the obtained CSI, we use it to decode the received data. Experiments verify our platform.

I. Introduction

Radio-based human behavior recognition has become a hot topic in recent year. Compared to video-based human recognition, radio-based approach can better protect our privacy. Compared to wearable devices based approach, radio-based approach can get rid of the trouble of contact [1].

Most current radio-based behavior recognition are in WiFi framework, such as WiDance [3], WiGest [2], WiFall [4]. This is because WiFi devices are ubiquitous and the channel state information (CSI) are easy to obtain. Most current radio-based behavior work in frequency below 6G. However, the accurate of recognition is proportion to the frequency of the radio. If we can use higher frequency radio, we can achieve finer recognition performance. Therefore, millimeter wave behavior recognition is worth studying as its high frequency and it is also a major tendency for next generation wireless communication.

Few works have study the millimeter wave behavior recognition because the scarcity of millimeter wave equipments. Google's millimeter wave gesture recognition is a nice work, but



(a) Transmitter (b) Receiver

Fig. 1. The millimeter wave channel sounding equipments made by KeySight Technology.

it use a dedicated chip and it can only bed used to recognition [5]. Since millimeter wave communication will be as universal in the future as WiFi in nowadays, we would like to research the CSI-based behavior recognition in millimeter wave band. However, no mature platform can be used to do this.

In this work, we build a millimeter wave behavior recognition platform. Fortunately, our school has a channel sounding equipment which is idle now. We can make full use it and built the platform based on the equipment. Once we have the platform, we can further our research and do many interesting things.

II. Off-the-shelf Channel sounding equipments

The channel sounding equipment is shown in Figure 1. It is composed of a series of standard instruments. A brief introduction of those instruments and the work flow are as follows.

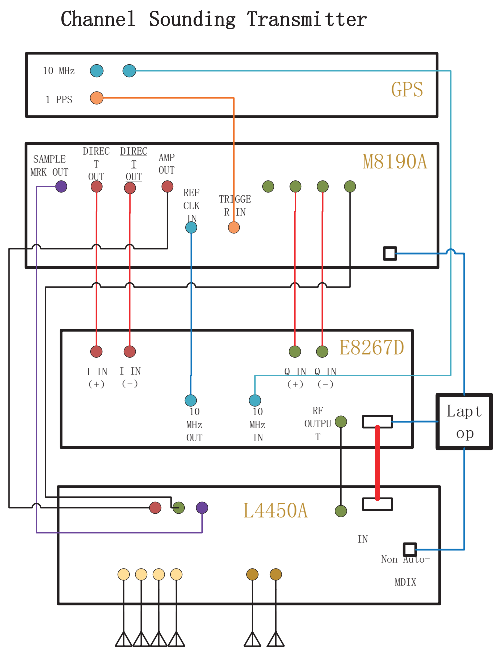


Fig. 2. The block diagram of the transmission system.

A. Transmitter

The transmission system consists of global position system (GPS) clock, arbitrary waveform generator (AWG) M8190A, PSG vector signal generator E8267D, digital I/O with memory and counter L4450A, 4 four 38G antennas, 2 2.6G antennas, and a laptop. The connection of those instruments is as Figure 2 illustrated.

The GPS clock can receive GPS signal and output extremely accurate clock signal of 10 MHz. It also generates 1 pulse per second (PPS) which can act as a trigger signal to synchronize the transmitter and the receiver.

In this transmission system, the laptop is the central controller. Firstly, it provides the base band I/Q data and sample marker which stores in a predefined file.Those data will be transfered to AWG M8190A. Secondly, it can control the equipments remotely with TCP/IP connection or USB connection. It will set the work mode and corresponding parameters of AWG M8190A, VSG E8267D and L4450A.

The AWG M8190A can not only generate analog base band signal according to the given data file, but also generate radio frequency (RF) signals in signal up-covert (DUC) model. If the carrier frequency is not too high, M8190A can generate RF directly and output the signal in the ports named AMP OUT. Thus the M8190A can provide two channels signals can transmit those signals in the two antennas separately. If higher carrier frequency is need, M8190A only generate analog differential based I/Q signals which are transfered to E8267D. E8267D will perform analog up-covert and output the one channel RF signal to L4450A. L4450A will output the one channel RF signal via one of the four transition antennas. The signal named SAMPLE MRK generated by M8190A acts as a trigger signal which can decide when to switch the transmission antenna.

The work flow of this transition system is: We firstly write a waveform file which contains the base band I/Q data and the SAMPLE MAR data. Then the M8190A will play this waveform repeatedly meanwhile the start is triggered by the 1 PPS signal. In one period waveform, the SAMPLE MAR signal only has one rising edge which decide the switch time of the transition antennas. Thus the four transmission antennas will transmit the waveform one by one and repeatedly.

B. Receiver

Typical channel sounding receive system contains following instruments: GPS clock, four receive antennas, quad downconverter M9362A, frequency reference M9300A, hybrid amplifier/attenuator M9362A, high-speed digitizer M9703A, PSG analog signal generator E8267D, and high performance embedded controller M9037A. The connection diagram is depicted in Figure 3(a).

The work flows of typical channel sounding receive is: The GPS provide 10MHz clock signal and 1 PPS signal for synchronization. The M9362A downconvert the RF signal from the receive antennas to intermediate frequency (IF) signal which will be amplified or attenuated by M9362A to proper range and then digitized by M9703A. M9703A will start digitization after detected the trigger signal which is given by 1 PPS signal in original design. The controller M9037A acquires the sample from M9703A and analyze the signals with softwares.

III. CHALLENGES

Although the channel sounding equipment is designed for measuring the wireless channel, we can't use this equipment directly due hardware limitation.

- The record length of the received signals is limited. In current configuration, the sample rate is fixed to 1 GS/s and the memory size of M9703A is only 64M sample per channel. Thus the maximal record length is about 64 milliseconds. However, the time during of human behaviors is in second level. Therefore, the record length is too short to conduct behavior recognition.
- Communication protocols are needed to be implemented by ourselves. The off-the-shelf channel sounding equipments are just a collection of hardware and have not embedded communication protocols, which means we have to implement most physical layer algorithm.

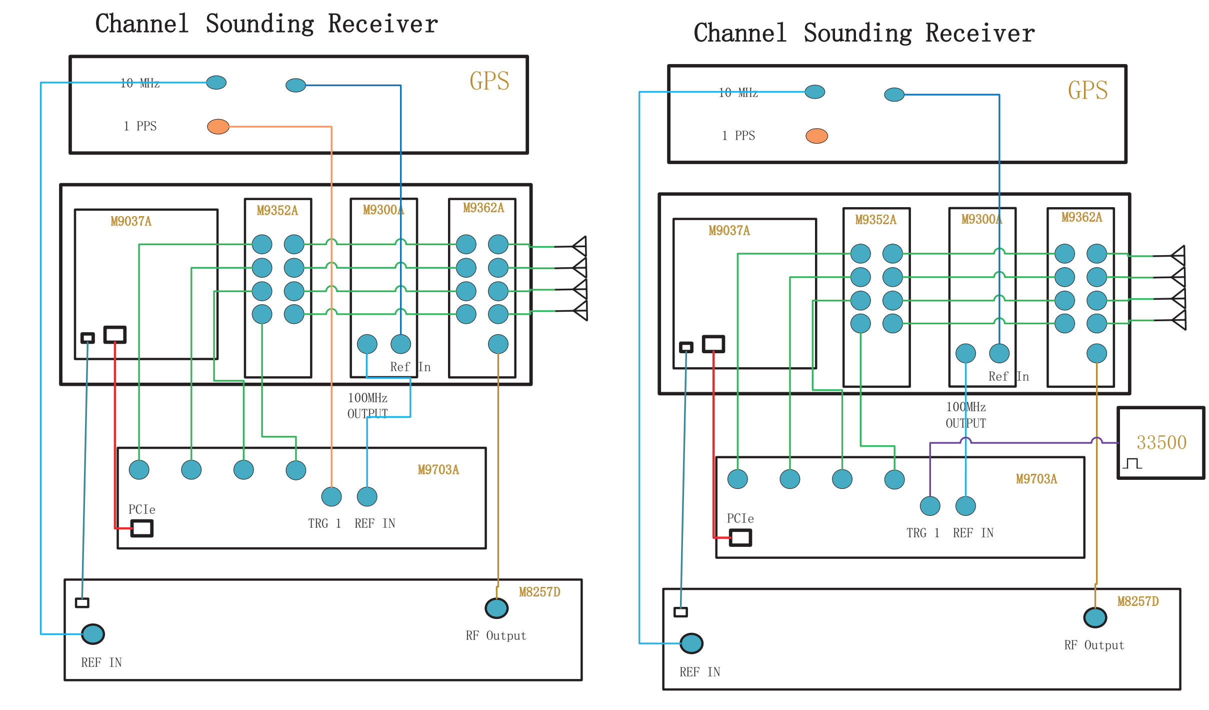
IV. Self-defined platform

To address the challenges, we modify the hardware and realize most of the physical layer algorithm.

A. *Increase the record length*

To increase the record length, we make some modification about the hardware. Firstly, we update the M9703A and enable it to conduct digital downconversion (DDC). Then the new M9702A will sample the base band data and the sample rate can be set to a much lower value. However, due to the limitation of memory size and Nyquist's law, the record length is still short if the M9703A continues sampling a nonnarrow-band signal. Considering the fact that the slow speed of human's movement, we do need to measure the CSI all the time. Instead, we can measure the CSI at a fixed frequency. To achieve this goal, we firstly change the trigger signal of M9703A to a pulse signal generated by 33500. The M9703A works in multirecord model and will record a predefined numbers of samples after received the trigger signals. The frequency of pulse signal will determine the CSI acquisition frequency. The new connection diagram is given in Figure 3(b).

Besides the changes in hardware, we write a control software to obtain the samples and store them into files. We program the control software based on IVI-COM driver using C# program language. The function of the software is to let M9703A to work as above model and give the interface of setting parameters. The panel of the software is as Figure 4 illustrated.



(a) Original diagram

(b) Current diagram

Fig. 3. The block diagram of the receive system.

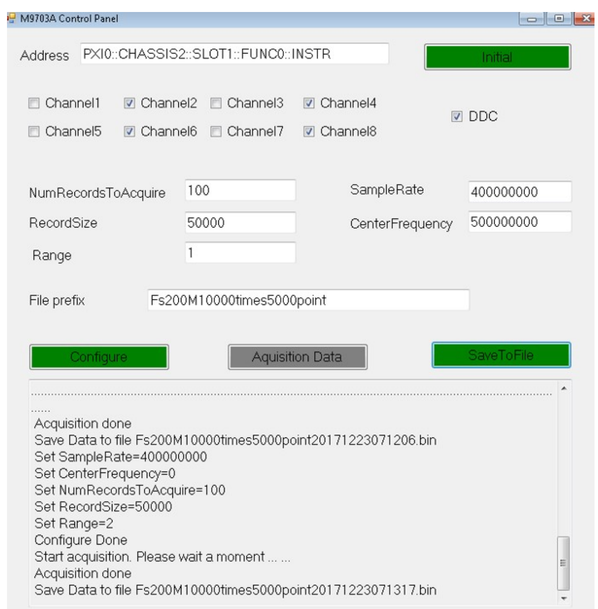


Fig. 4. The panel of our control software for M9703A.

B. Communication protocols

This system can only works in simplex mode since the transmitter and receiver can two different equipments. In transmitter side, we just need to prepare the base band waveform file and transmit it periodically. We adopt the widely used OFDM scheme and QPSK modulation. We use the similar frame structure as in NBIoT [6] except the sample rate. we transmit 10 frame : the first frame is nonnarrow-band primary synchronize signal (NBPSS), the second, forth, sixth,eighth and tenth frame are QPSK signals, the other frames are set to zeros.

In the receiver side, the procedure is much more complicated. For each record, we have to synchronize firstly. We need to find the find a complete cope of received one period signal and find the start point. Then we do sample timing offset (STO) correction and carrier frequency offset (CFO) correction. After that, we do channel estimation and decode the transmitted data to verify the correctness.

- Synchronization. Assume the transmit waveform is $\boldsymbol{x} \in \mathcal{C}^N$, the receive waveform is $\boldsymbol{y} \in \mathcal{C}^M$. Then we do correlation, $\boldsymbol{c}(n) = \sum_{k=0}^{N-1} \boldsymbol{x}(k)^* \boldsymbol{y}(n+k)$. The start point of can be find by $s = \arg max_n |\boldsymbol{c}(n)|$.
- STO estimation. We use NPSSS to estimate the STO. Assume the transmitted OFDM frequency domain symbol is $\boldsymbol{x}$, where the data in each tone have unit amplitude. The receive symbol is $\boldsymbol{y}$. Then we do IFFT of $\boldsymbol{y} \cdot \boldsymbol{x}^*$ and then find the shift, which is the STO.
- CFO. We use Moose algorithm [7] to estimate the CFO with NPSSS as reference signal.
- Chanel estimation. We normalize the transmitted signal and simply use the sample mean as estimation. More complex algorithm, such as MMSE, kalman filter can be used here to get more accurate CSI [8].

V. EXPERIMENT RESULTS

To verify our platform, we transmitted the above OFDM signal, and decode the bit information. The transmitted signal is as Figure 5 illustrated. Then the detected one period received waveform is depicted in Figure 6. We do channel estimation, and decode the QPSK signal, the bit error rate is shown in Table I. When there are no people here, the bit error rate is 0.0022. This is small since the transmit speed is set to 400Mbits and we just use the simplest channel estimation algorithm. Where there exist moving human the bit error rate gets higher as the channel changes faster. This can be seen in Figure 7.

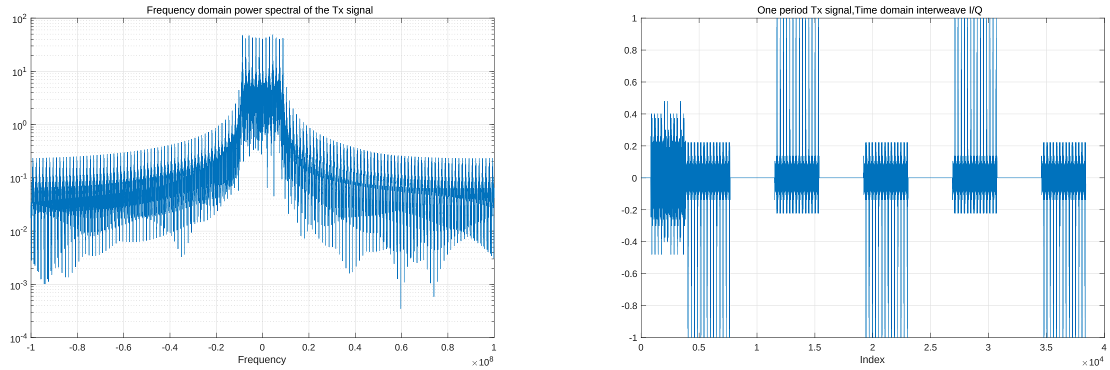


Fig. 5. Transmitted OFDM signal.Left: frequency domain power spectral. Righttime domain interweave I/Q samples.

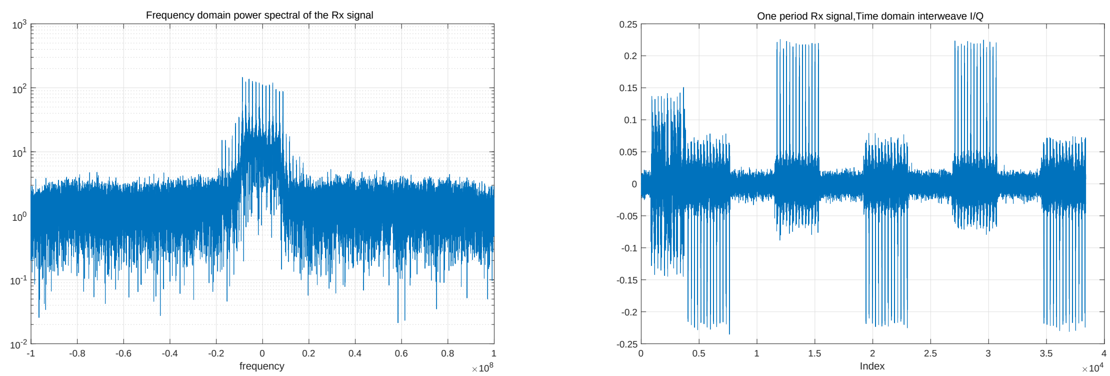


Fig. 6. Deteected one period received signal.Left: frequency domain power spectral. Righttime domain interweave I/Q samples.

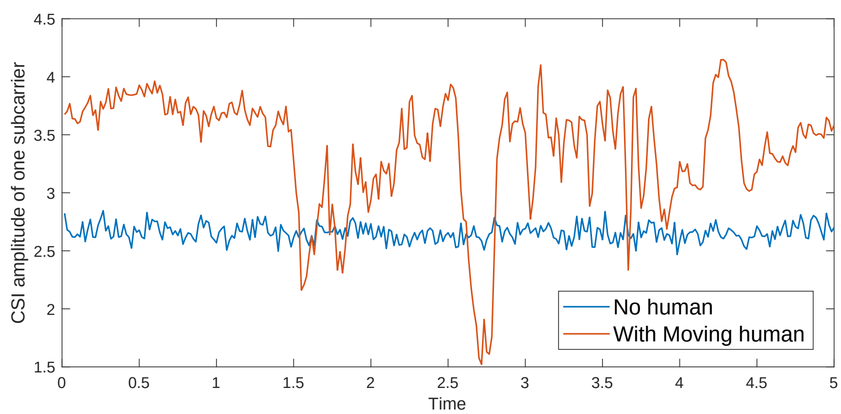


Fig. 7. The amplitude of CSI on one subcarrier in two situation. When there is no human, the CSI changes slowly. When there is moving human, the CSI change faster.

TABLE I

PLEASE WRITE YOUR TABLE CAPTION HERE

Situation	Bit error rate
No human	0.0022
Moving human	0.0042

VI. CONCLUSIONS

In our project, we build a millimeter wave behaviors recognition platform. We modify the off-the-shelf channel sounding equipments, allow it to record much longer data. We write a control software to acquire data from hardware. We also implement a completed OFDM transmission framework and the corresponding synchronization algorithm. We estimate the channel and then use it to decode the data. Experiment results verify our design.

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