Research and Implementation on OFDM Technology for Machine Communication

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Abstract. Machine communication provides the means of information interaction for Internet of Everything (IoE) and unattended operation, promoting the development on the related areas such as Internet of Things, automatic drive, robot, and unmanned aerial vehicle (UAV) which are on this basis. In machine communication on a large scale, mass user multiplexing will give rise to high peak-to-average ratio (PAR) of OFDM and redundant control information will lower the utilization efficiency of OFDM’s effective frequency. In the light of the problems above, OFDM optimization technique used in machine communication is put forward in this thesis. Under the circumstances of more user access currently, more complex application context, high PAR and low utilization efficiency, the thesis proposes computer emulating by OFDM and optimization of access mode. Additionally, OFDM optimization technique, applying partial transmit sequence and carrier to noise ratio (CTNR) to realize the redundant information control of short frame carrier, optimize PAR and enhance the transmission efficiency. Finally, simulation experiment and hardware design verify the feasibility of OFDM optimization technique in machine communication.

1. Introduction

Through sensors and communication devices, machine communication endows the ability of perception and transmit ability to machine, which realizes machine to machine communication, organization and management, providing a means of information interaction for IoE and unattended operation.

As there is an effective solution for data transmission between machines, machine communication will promote the development on related areas such as IoT, automatic drive, robot, UAV, intelligent measurement, industrial automation, intelligent monitoring and wearable devices which are on this basis.

Machine communication and its key technology have been the emphasis of IoT and academic research around the world. In 2010, Defense Advanced Research Projects Agency (DARPA) started LANdroids, aiming at resolving radio relay technology problem of mobile tactics based on networking between machines during NLOS fighting in the city environment. In 2015, European Union enacted eCall initiative, stipulating that machine communication devices need to be installed to track vehicle parts and interactive status in real time. IBM put forward the concept of intelligent city which links cites intelligently by IoT technology based on machine communication. When ITU and 3GPP set mobile communication standard 5G, mass machine communication was defined as one of the three application context of 5G. In 2019, Ministry of Internal Affairs and Communications in Japan planned to set 10 billion 14-bit digital IDs used as identifiers in machine-machine communication. Since the 11th Five-Year Plan, China has deployed a large amount of projects about basic research and key technology, planning to tackle the core problems of machine-machine communication.
The scale of connection is the important symbol of the development of communication technology between machines and its development trend includes single-point machine communication, multi-point machine communication and mass machine communication. As for single-point machine communication, based on transceivers such as RFID and infrared, it reports information after perceiving a single task, with the advantages of low cost and convenient deployment, but it can only support one-to-one machine communication. Multi-point machine communication is a way of IOT gathered by WI-FI, lora, NB-IoT etc. which have network central node. Networking some machines by networking protocol, this kind of communication way can support multi-point machine communication, but the quantity and flexibility of machines that the network can bear are insufficient. Mass machine communication is based on 5G, adopting flexible sub-carrier and frame structure to realize information interaction between massive machines in broadband.

In conclusion, there are two problems in mass machine communication. Problem 1: massive user multiplexing will give rise to high PAR of OFDM. Problem 2: redundant control information will lower the utilization efficiency of OFDM’s effective frequency.

In respect of the problems above, this thesis puts forward OFDM optimization technology in machine communication. Under the circumstances of more user access currently, more complex application context, high PAR and low utilization efficiency, the thesis proposes computer emulating by OFDM and optimization of access mode. Additionally, OFDM optimization technique, applying partial transmit sequence and carrier to noise ratio (CTNR) to realize the redundant information control of short frame carrier, optimizes PAR and enhances the transmission efficiency. Finally, simulation experiment and hardware design verify the feasibility of OFDM optimization technique in machine communication.

2. Basic Theory of Machine Communication and OFDM Technology

2.1 Relevant Technology Researches on Machine Communication

In 5G context of 3GPP positioning, machine communication is for devices with low power consumption, small volume and large scale, so technological problems like power control, signal compression and capacity enlargement should be overcome in machine communication.

Suppose that the context of machine communication is $\Omega$, and then in $\Omega$, there exists $k$, a kind of device needs communication, recorded as $K_1, \ldots, K_k$. Each kind of device contains $N_k$. For the quantity of machine communication is large, $N_k$ should be greater than $10^6$. Suppose that signal transmitting power of each machine is $A_k,N_k$, and it meets the condition $A_k,N_k < AT_k$ which means that signal transmitting power of each machine should be lower than the lowest power threshold value of each kind of machine, $AT_k$.

Base station, the integration of communications by multiple machines, needs to meet the condition that each machine communication power sum should lower than the lowest threshold value of base station’s power receiving,

$$ AT_{gmb} < \sum_{k=0}^{n} A_k,N_k $$

(1)

where $n$ refers to the quantity of machine communication in the same base station. Therefore, SixFox model in 3GPP pays attention that power control is launched from machine instead of base station, which lowers power consumption in waking up paging channel.

Operational capability and storage capacity of each device are limited because of the volume, so the information that can be sent and processed is limited. Suppose that the sending information in machine communication is $S$, which can be divided into $S_c$, the control information and $S_u$, the user information, also the effective information in machine communication. As a general rule, Only by controlling information $S_e$ on UE side and network side over and over again every time, can machine communication finish the transmission of $S_u$, and its efficiency of communication can be recorded as

$$ \eta = S_u / (S_u + pS_c) $$

(2)

$p$ refers to the number of interactive time for one communication. 3GPP sets up a new radio resource allocation mode which can maintain the connection of control signaling under the idle state. Therefore, the connected machine can finish information transmission when the number of time of control
interaction is less than $p$, and then the $\eta$ increases.

2.2 Relevant technological research on OFDM

In 5G, information in machine communication is carried by radio resources of OFDM. Control information $S_c$ and user information $S_u$, the transmit information in machine communication, can be gained from 2.1. And then, by Fourier transform, the formula in discretization after serial printer conversion is shown as below.

$$s(t) = \sum_{i=0}^{N-1} \frac{1}{\sqrt{N}} (S_c + S_u) \times \exp(j2\pi \frac{i}{N} t)$$  \hspace{1cm} (3)

In the formula, $t = kT/N (k = 0, 1, ..., N - 1)$, $i$ is the number of sub-carrier of OFDM, representing that transmit information will be carried on $i$ orthorhombic carrier(s). $T$ is the cycle of each sub-carrier, deciding the frequency of sub-carrier. $N$ is the number of information symbol, where control information $S_c$ includes Transmission overhead of OFDM and control overhead of machine communication.

According to the description of signal features of machine communication of OFDM in formula (3), we can know that the control information and user information of machine communication are carried on mutually orthorhombic sub-carrier. Dominant frequency of each sub-carrier is different and they are in mutual orthogonality without interference. In consequence, using different number of sub-carrier for composite transmission of information can effectively solve the problem of wasting of resources brought by short information length in machine communication.

After modulation and multiplexing, up-conversion of IF signal can be done, which is shown as

$$y(t) = A \times s(t) \times \cos(2\pi ft)$$  \hspace{1cm} (4)

At this time, $A$ is $A_{k.N_k}$ based on the lowest power threshold value $AT_k$ of each kind of machine.

A. The existing problems of OFDM technology applied in mass machine communication

As a general rule, adopting OFDM technology will lead to high power obviously, which refers to the problem of high PAR. The definition of PAR is shown as below:

$$PAPR = \frac{\max_P[P(t)]}{E[P(t)]}$$  \hspace{1cm} (5)

$P(t)$ is the power of signal $s(t)$, referring to $|s(t)|^2$. $\max_P[P(t)]$ is the maximum power of OFDM signal in one period and $E[P(t)]$ is the average power of OFDM in this period. In OFDM, orthorhombic sub-carriers are used. For the phase difference between two adjacent sub-carriers, superposition of time domain is different, which specifically shows that in-phase are in superposition, out-phase offsets. Due to the randomness of phase, phase coincidence of adjacent sub-carrier will upgrade the signal peak value. Based on the formula (4), in machine communication, when $A_{k.N_k}$ is large, PAPR will occur; and at the same time, the quantity of machine communication is large, which will bring more phase allocated randomness and further increase PAPR.

High PAPR will make the signal enter the no-linear area of power amplifier devices, lowering transmission gain. Therefore, the technology with high efficiency for lowering PAPR of machine communication needs to be explored.

3. OFDM Optimization Technology with Combination of Partial Sequence Transmission and Carrier Aggregation

3.1 PAR Optimization of OFDM with Phase Optimization and Clipping

The main reason of high PAR of OFDM is that power of sub-carriers in-phase can add together in the time domain after superposition, thus it is significant to lower PAR of OFDM by information sequence inhabiting the in-phase phenomenon. The thesis aims for lowering the overall PAR through cutting carriers with high PAR and choosing suitable factors to rotate phase. In details, the input data $S$ will be divided into $n$ groups and each group can recombine adjacent data based on phase factors. According to the situation, each kind of PAPRR can be calculated and the lowest PAPR will be chosen as the configuration method of sub-carrier phase. At this time, if high PAPR still exists, the corresponding data will be clipped. The specific process is shown as figure 1.
Figure 1. PAR Control of OFDM Combining with Phase Optimization and Clipping

1) Dividing the input data into n group(s) sub-data blocks which are complementary and overlapping;

2) Combining n branch circuit sub-data with phase rotation factors respectively and n IF signal(s) will be generated;

3) According to formula (5), each branch circuit of power and PAR can be calculated;

4) Choosing the lowest PAR of signal, referring to $s_{\text{out}}(t) = \arg \min (s(t))$;

5) Clipping $s_{\text{out}}(t)$, and at this time the lowest threshold value is $\Delta T_k$.

3.2 Control of Redundant Information with short-frame Carrier Aggregation

Because of the small length of control signaling in machine communication, short data frame is often adopted as the carrying way. Sub-carrier and time slot of OFDM can be used as the carrying resource block of control signaling in machine communication. If these resource blocks use sub-carriers to directly finish mapping, it is easy to cause RB waste. In order to further make good use of the advantages of OFDM on fragmentary resources, many machine communication tasks can be aggregated. Additionally, resource blocks of OFDM can be used uniformly to generate the long data frame within a frequency band in a certain time period.

In fact, processing the long data frame is to make parallel group of different control information of machine communication as the serial data processed by partial sequence transmission. Control short frame with different length can reach the bit length of phase rotation factors after processing by zero filling. At this time, by adjusting the position of machine communication data, many new circuits of signal ways can be obtained, and then the lower PAR can be obtained.

Figure 2 Short-Frame Carrier Aggregation
3.3 PAR Analysis
In Matlab, OFDM communication system environment based on machine communication is set up. The system composition is shown as figure 3.

![System Model set up in Matlab](image)

Figure 3 The System Model set up in Matlab

The system mainly includes transmitter of IoT device, wireless communication channel, receiver of IoT device and performance analysis module. The key indicator of considerations is PAR of signal. The PAR performance of OFDM with phase optimization and clipping is shown as figure 4.

![PAR performance of OFDM with phase optimization and clipping](image)

Figure 4. The PAR performance of OFDM with phase optimization and clipping

By choosing suitable phase, optimal performance of OFDM signal can be obtained. As is shown in figure 4, when the number of group is 4 and CDF (cumulative distribution function) is $10^{-3}$, PAR calculated by the new algorithm is 7.9dB while PAR before optimization is 10.7dB, which shows that the new algorithm makes optimizing of 2.8dB.
4. Hardware Implementation of FPGA

4.1 Simulation environment
In order to further verify the new algorithm, the thesis verifies OFDM with phase optimization and clipping in FPGA. The development environment is simulation environment of circuit function Modelsim and FPGA testing software Quartus.

4.2 Hardware Implementation Function and Output Situation
The hardware functional framework of OFDM mainly contains control module, training sequence generating module, Signal symbol generating module, Data symbol generating module, pilot carrier inserting module, IFFT module and so on.

➢ Hardware implementation of clock module
6 clock signals with different frequency which are needed by OFDM system are generated, where 7.5MHz clock is obtained by dividing 60MHz clock for 8 times. When LOCKED signal is at the high level, all the clock signals are stably output, shown as figure 5.

![Figure 5. Clock signals’ output of OFDM](image)

➢ Hardware Implementation of the main control module
MCU, the main control module is the important part of the whole transmitter, generating different kinds of control signals, which enables each module of the transmitter to operate orderly and accurately, so MCU unit adopts counting method to output various control signals. In addition, physical layer data of OFDM system is gained from the network layer. MCU also can connect or interrupt the communication between physical layer and network layer.

➢ Hardware module of parallel-serial conversion
The function of parallel-serial conversion module is converting 8-bit parallel data into serial data. Physical layer data of OFDM is obtained from network layer and data of network layer transmit in the form of bytes, so physical layer should pass a serializer to convert the data in byte format into serial-binary bit data.

➢ Scrambling Code Module
Scrambling Code is a kind of code processed regularly. Because during the signal transmission process, “0” or “1” will input for more than one time, which will lead to the increase relevance of signal. Therefore, it will affect the start bit of testing symbol of timing and synchronization module in receiver. For this reason, signals for transmission need to be lower the relevance by scrambling module to make the signals become data flow similar with white noise.

After Signal symbol generating module is generated, long training sequence of OFDM can be output, shown as figure 6.
5. Conclusion
The thesis focuses on OFDM optimization technology in machine communication, proposing that by computer emulating, the access way can be optimized. Using OFDM optimization combining partial sequence transmission with carrier wave ratio, redundant information of short frame carrier can be controlled, PAR can be optimized and transmitting efficiency can be improved. By emulating experiment and hardware design, OFDM optimization technology is verified as the practicable way. The optimization technology proposed in this thesis can effectively solve the problem of high PAR and low using efficiency in machine communication.

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