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ANALYSIS OF EFFECT OF CYCLIC PREFIX ON DATA RATES IN OFDM MODULATION TECHNIQUES

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ABSTRACT

4G – network systems require higher reliability and high spectral efficiency. To achieve this Orthogonal Frequency Division Multiplexing (OFDM) is considered to be the best modulation technique for 4G- networks. OFDM can provide large data rates with sufficient robustness to radio channel impairments. OFDM is designed such a way that it sends data over hundreds of parallel streams which increases the amount of information that can be sent at a time. It can offer high quality performance in terms of bandwidth efficiency, robustness against multipath fading and cost-effective implementation. A guard time, in the form of cyclic prefix (CP), is inserted between OFDM symbols to eliminate both the inter-symbol interference (ISI) and the inter-channel interference (ICI). In this paper we have studied the effect of cyclic prefix on data rate using OFDM modulation techniques. Simulation is performed using NS2 simulator by taking case of 802.16 networks.

Keywords: *WiMAX, OFDM, Cyclic prefix, Multi-Carrier Modulation, 4G – Networks, etc.*

[I] INTRODUCTION TO OFDM

Orthogonal Frequency Division Multiplexing is a method of encoding digital data on multiple carrier frequencies. Since it saves the need for complex equalizers, it is best suited for channels with a nonflat frequency response [10]. The OFDM technique allows a base station to split a chunk of radio spectrum into sub-channels. The signal strength of the sub-channels and the number of channels assigned to different devices can be varied as needed. OFDM allows high data rates, even far from a base station. Hence it suits well with the type of radio interference that is common in urban areas, where signals reflect off walls to produce confusing echoes [3].

The idea of OFDM is derived from Multi-Carrier Modulation (MCM) transmission technique. The principle of MCM is that to divide the input bit stream into several parallel bit streams and then they are used to modulate several sub carriers. Guard band is used to separate the sub-carrier so that they do not overlap with each other. Bandpass filters are used at the receiver side, to separate the spectrum of individual sub-carriers. OFDM is a special form of spectrally efficient MCM technique, which involves densely spaced orthogonal sub-carriers and overlapping spectrums. Due to orthogonality nature of the sub-carriers, the use of bandpass filters is not required in OFDM. Hence, the available bandwidth is used very efficiently without causing the Inter-Carrier Interference (ICI) [8].

Multipath generates two effects: frequency selective fading and intersymbol interference (ISI). The "flatness" perceived by a narrow-band channel overcomes the frequency selective fading. Modulating at a very low symbol rate makes the symbols much longer than the channel impulse response and eliminates the effect of ISI. Using powerful error correcting codes together with time and frequency interleaving gives even more robustness against frequency selective fading and the insertion of an extra guard interval between consecutive OFDM symbols can reduce the effects of ISI even more. Thus, an equalizer in the receiver is not necessary [2]. The wireless communication systems are susceptible to multipath channel reflections, and due to this reason a cyclic prefix is added to reduce ISI. A cyclic prefix is a repetition of the first section of a symbol that is appended to the end of the symbol. In addition, it is important because it enables multipath representations of the original signal to fade so that they do not interfere with the subsequent symbol.

1.1 WORKING PRINCIPLE OF OFDM

The basic principle of OFDM is to split a high-rate datastream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Intersymbol interference is eliminated almost completely by introducing a guard time in every OFDM symbol. In the guard time, the symbol is cyclically extended to avoid intercarrier interference [11].

An OFDM signal is a sum of subcarriers that are individually modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM). The symbol can be written as:

$$s(t) = Re\left\{\sum_{i=\frac{N_s}{2}}^{\frac{N_s}{2}-1} d_{i+N_s/2}\exp\left(j2\pi\left(f_c - \frac{i+0.5}{T}\right)(t-t_s)\right)\right\}$$

$$t_s \le t \le t_s + T$$

$$s(t) = 0, t < t_s \, and \, t > t_s + T \quad \rightarrow \text{(i)}$$

where :

N_S is the number of subcarriers

T is the symbol duration

f_c is the carrier frequency

1.2 SIGNAL CHARACTERISTICS

An OFDM signal consists of *N* orthogonal subcarriers modulated by *N* parallel data streams. Each baseband subcarrier is of the form

$$\emptyset_k(t) = e^{j2\pi f_k t} \quad \rightarrow \text{(ii)}$$

Where, f_k is the frequency of the k^{th} subcarrier. One baseband OFDM symbol (without a cyclic prefix) multiplexes *N* modulated subcarriers:

$$S(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x_k \emptyset_k(t), 0 < t < NT \quad \rightarrow \text{(iii)}$$

Where x_k is the k^{th} complex data symbol and *NT* is the length of the OFDM symbol. The subcarrier frequencies f_k are equally spaced and it is given by the following equation,

$$f_k = \frac{k}{NT} \quad \rightarrow \text{(iv)}$$

which makes the subcarriers $\emptyset_k(t)$ on $0<t<NT$ orthogonal. The signal (iii) separates data symbols in frequency by overlapping subcarriers, thus using the available spectrum in an efficient way.

The OFDM symbol (iii) could typically be received using a bank of matched filters. T-spaced sampling of the in-phase and quadrature components of the OFDM symbol gives-

$$S(nT) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x_k e^{j2\pi\frac{nk}{N}}, 0 \le n \le N-1 \rightarrow \text{(v)}$$

which is the Inverse Discrete Fourier Transform (IDFT) of the constellation symbols x_k. Accordingly, the sampled data is demodulated with a DFT.

1.3 CYCLIC PREFIX IN OFDM

OFDM data are generated by taking symbols in the spectral space using M-PSK, QAM, etc, and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). After, OFDM data are modulated to time signal, all carriers transmit in parallel, so that all the available frequency bandwidth is fully occupied [1]. During modulation, OFDM symbols are divided into frames, which makes the data will be modulated frame by frame in order for the received signal be in sync with the receiver. In order to eliminate ISI, a cyclic prefix is added to each symbol period. An exact copy of a fraction of the cycle, typically 25% of the cycle, taken from the end is added to the front. This allows the demodulator to capture the symbol period with an uncertainty of up to the length of a cyclic extension and still obtain the correct information for the entire symbol period. Cyclic extension is the amount of uncertainty allowed for the receiver to capture the starting point of a symbol period, such that the result of FFT still has the correct information.

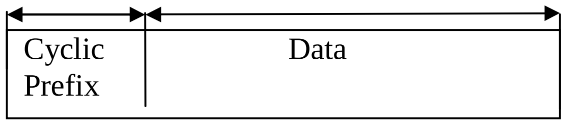

Fig 1: Cyclic prefix in ODFM

When a guard period is inserted between consecutive OFDM signal, containing cyclic extension of the OFDM symbol, the OFDM signal (iii) is extended over a period Δ so that, equation (iii) is written as follows:

$$s(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x_k e^{j2\pi f_k t} \quad -\Delta < t < N \rightarrow \text{(vi)}$$

The signal then passes through a channel, modeled by a finite-length impulse response limited to the interval [0, Δ_h]. If the length of the cyclic prefix Δ is chosen such that $\Delta > \Delta_h$ the received OFDM symbol evaluated on the interval *[0, NT]*, ignoring any noise effects, becomes

$$r(t) = s(t) * h(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} H_k x_k e^{j2\pi f_k t}, \quad 0<t<NT \quad \rightarrow \text{(vii)}$$

Where $H_k = \int_0^{\Delta_k} h(T)\, e^{j2\pi f_k t} dT \quad \rightarrow$ (viii)

Equation (viii) is the Fourier transform of *h(t)* evaluated at the frequency f_k. Within this interval the received signal is similar to the original signal except that $H_k x_k$ modulates the k^{th} subcarrier instead of x_k. In this way the cyclic prefix preserves the orthogonality of the subcarriers.

Equation (vii) suggests that the OFDM signal can be demodulated by taking an FFT of the sampled data over the interval *[0, NT]*, ignoring the received signal before and after $0 < t \le NT$. The received data then has the form

$$y_k=H_k x_k \qquad k=0,\dots,N-1 \qquad \rightarrow \text{(ix)}$$

The received data in Equation (ix) can be recovered with N parallel one-tap equalizers. This simple channel equalization motivates the use of a cyclic prefix and often the use of OFDM itself. Because we ignore the signal within the cyclic prefix this prefix also acts as the above mentioned silent guard period preventing ISI between successive OFDM symbols.

The use of a cyclic prefix in the transmitted signal has the disadvantage of requiring more transmit energy. The loss of transmit energy due to the cyclic prefix is

$$E_{loss} = \frac{NT}{NT+\Delta} \qquad \rightarrow \text{(x)}$$

This is also a measure of the bit rate reduction required by a cyclic prefix. That is, if each subcarrier can transmit b bits, the overall bit rate in an OFDM system is Nb/(NT+Δ) bits per second as compared to the bit rate of *b/T* in a system without a cyclic prefix. If latency requirements allow, these losses can be made small by choosing a symbol period *NT* much longer than the length of the cyclic prefix Δ.

[II] SIMULATION METHOD

The simulation is done using NS2 simulator. Network simulation is commonly used for the evaluation of wireless network protocols. Discrete event simulators typically model the network activities on a packet-by-packet basis, in time granularity of terms of microseconds, and include a model for each layer of the entire protocol stack. NS is a discrete event simulator written in C++, with an OTcl interpreter shell as the user interface that allows the input model files that is, Tcl scripts, to be executed. NS provides support for simulation of TCP, routing, and multicast protocols over wired and wireless networks.

In our simulation NS2.29 version is used and it is performed by on WiMAX network. The parameters used are as shown below:

The parameter of wireless channel in tcl script is as given below:

```
#channel type
Phy/WirelessPhy/OFDM      set      value
#500m radius
Phy/WirelessPh  set    RXThresh_ 2.025e-12;

# Parameter for wireless nodes
# channel type
set opt(chan)       Channel/WirelessChannel;
# radio-propagation model
set opt(prop)     Propagation/TwoRayGround;
# network interface type
set opt(netif)        Phy/WirelessPhy/OFDM;
# MAC type
set opt(mac)               Mac/802_16;
# interface queue type
set opt(ifq)       Queue/DropTail/PriQueue;
# link layer type
set opt(ll)          LL;
# antenna model
set  opt(ant)         Antenna/OmniAntenna;
# max packet in ifq
set opt(ifqlen)             50;
# routing protocol
set opt(adhocRouting)   DSDV;
```

During our simulation we used cyclic prefix to minimize the Inter Symbol Interference (ISI) on the basis of following adaptive modulation techniques –

- Binary Phase Shift Keying (BPSK)
- Quadrature Phase Shift Keying (QPSK)
- 16-Quadrature Amplitude Modulation (16-QAM)
- 64-Quadrature Amplitude Modulation (64-QAM)

[III] RESULTS:

The graph drawn cyclic prefix vs. data rate is as shown below.

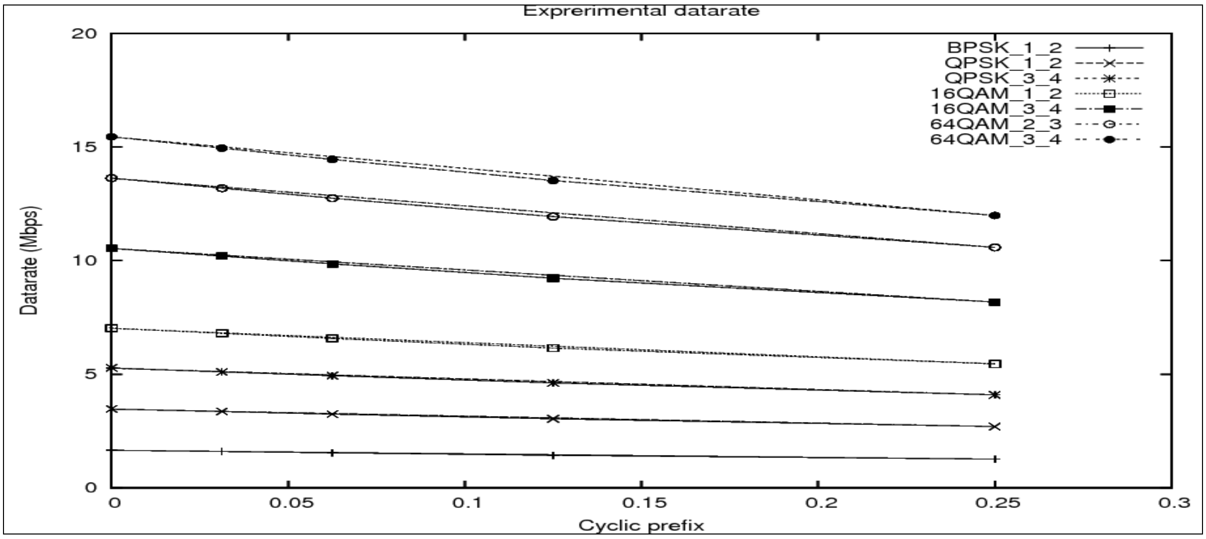

Fig 2: Graph of cyclic prefix vs. data rate.

The Cyclic Prefix is key player in WiMAX Network. It is observed that the modulation scheme and Cyclic Prefix have the significant effect on the performance of WiMAX network. The Cyclic Prefix plays an important role to increase and decrease the data rate in WiMAX. By using different cyclic prefixes it is possible to increase or decrease the data rate in WiMAX network. By increasing the value of Cyclic Prefix the data rate of WiMAX network decreases. In other words by decreasing the value of cyclic prefix it is possible to increase the data rate. Higher Cyclic Prefix means large time gap between two frames and large Cyclic Prefix give extra time to receive signal from multipath channel. So the selection of Cyclic Prefix value is based on the coverage area that would be covered by the signal and keeping data rate parameter in consideration.

[IV] CONCLUSION

In this paper we have discussed issues related to cyclic prefix in OFDM and simulated the effect of cyclic prefix on data rate in IEEE 802.16. Orthogonal frequency division multiplex (OFDM) modulation is being used mostly in telecommunication, wired and wireless. OFDM can be implemented easily, it is spectrally efficient and can provide high data rates with sufficient robustness to channel imperfections. Due to these reasons OFDM playing an important role in 4G – Networks as it requires higher data rates. It is a block modulation scheme where a block of N information symbols is transmitted in parallel on N sub-carriers. A guard time, usually in the form of cyclic prefix (CP), is inserted between OFDM symbols to eliminate both the inter-symbol interference (ISI) and the inter-channel interference (ICI). Transmission of cyclic prefix reduces the data rate. From the graph it is clear that as cyclic prefix duration increases the data rate decreases; hence the cyclic prefix duration should not be much more than the duration of the maximum expected multipath channel.

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