# Realization of LTE-A System with FTN Algorithm

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***Abstract*—Mobile communications has become one of the most developed technologies in the last two decades. Strong demand to increase system capacity is still growing dramatically .LTE-Advanced (LTE-A) is an emerging and a more advanced set of standards and technologies that will be able to deliver bigger and speedier wireless-data payloads. These LTE-A systems can be implemented with 5G algorithms. One of the promising 5G algorithm is a non-orthogonal transmission scheme Faster-Than-Nyquist (FTN) signaling. In this paper, the faster-than-Nyquist (FTN) signalingis surveyed, the basic principles and the system framework of FTN signaling are presented and more details on transmitter and receiver optimization are discussed.**

***Keywords*—FTN, Bandwidth efficient, LTE-A, 5G algorithm, transmitter design, receiver design.**

## I. INTRODUCTION

The development of fourth generation (4G) mobile communications, also known as Long-Term Evolution(LTE) or Evolved Universal Terrestrial Radio Access(E-UTRA), has been accepted as the latest solution for the user demand of faster, reliable and efficient communication systems. The latest trend in the use of these services has clearly showed the rapid increase in the demand of more promising approaches. In general, this requirement of high wireless data traffic is expected to increase dramatically by more than 500 times within 2020 as compared to present traffic. Though the present technology can handle the situation for few more years, yet the large growth experienced in wireless communications has challenged the researchers to develop novel and innovative ideas more efficient than current LTE advanced technologies. The present radio access techniques thus require an adoption of more advanced technological means and the spectacular improvement. Baseband transmission of a digital signal is expected to maintain high speed data and good quality service on the background of low-pass channel with an extremely wide bandwidth. However, the real world scenario is not always as desired because of the limited resources of the spectrum availability. Frequency band requirement is directly proportional to the signaling speed, and therefore bandwidth scarcity has become an important concern. High speed and high quality data services with an integration of variety of communicating standards are important prerequisites for future wireless communication systems. Although due to the latest developments in the technical aspect of wireless communications has helped to increase the performance out of available bandwidth spectrum, it has to be accepted with very high cost for the mobile operators to pay for the allocated spectrum resources. Limited radio spectrum provided by the regulatory organizations has complicated the task of system design to meet the very fast pace evolutional growth of communication technology. This has posed a great need for an efficient bandwidth management.

Faster than Nyquist signaling (FTN) is under the greatest interest of research to address this issue of high data rate, which is also a major requirement of the fifth generation(5G) communication networks. The data bits are transmitted at a rate higher than the conventional methods which are bounded by the Nyquist condition and the outputs are compared so as to analyze the benefits. Considering the bandwidth efficiency as a key factor, more data symbols are sent at the given time interval by reducing the time period for signal transmission. This ensures more data being transmitted. In the scenario of perfect Nyquist signaling, pulse designs were based on the principle of orthogonality. The signal pulse form h(t) is orthogonal with respect to shifts by nT, where T is the signaling interval. In the this FTN, the time period is reduced to $T < 1$, which prompt more symbols to be transmitted. The pulses are no longer orthogonal. These non orthogonal FTN signals are accepted as a promising approach for the required solution of increased data rate. FTN comes as a tradeoff between the high data rate achievement and error probability. Reduction of the time factor affirms good data rate but at the same time, cost of high error rate has to be paid. Efficient receiver processing techniques can be designed to compensate between these two factors. Main obstacle due to the reduction of time period in FTN signaling is to tackle the unavoidable inter symbol interferences (ISI). Going beyond the Nyquist bound, as a consequence, results high ISI. This necessitates an effective receiver processing to overcome the ISI. Efficient encoding pattern and decoding algorithm helps in reducing the errors.

## II. FTN SIGNALLING

In this section, the basic principles of FTN signaling will be discussed.

### A. FTN SIGNALS

The concept of FTN as quoted by J. E. Mazo [1] in 1975 gives a motivation to study its optimal performance criteria when the signal transmission is carried out at the rate faster than the conventional rate which is satisfied by the

Nyquist condition. According to Mazo, increasing the rate of transmission of the signal by 25% more than given by Nyquist rate does not degrade the minimum Euclidean distance. In otherwords, Mazo clarifies that for Sinc pulses, in binary signal transmission, even with the increase in the signaling speed or increasing the rate of data transmission beyond the Nyquist signaling condition, minimum Euclidean distance does not reduce much. FTN refers to the system in which the signal is transmitted with the symbol interval T0 < T, where T refers to the symbol interval for the condition which satisfies Nyquist criteria and T0 is the new symbol interval for FTN. Reducing the symbol interval converts the Nyquist orthogonal pulses to non-orthogonal. This mechanism offers an advantage that more symbols can be transmitted in a given time frame as compared with the conventional arrangement. Thus more information can be transmitted at the rate faster than prescribed by Nyquist criteria. The equation for system with ordinary Nyquist condition

$$y(t) = \sqrt{Es}\sum_n x[n]\cdot h(t-nT) \qquad (1)$$

can be modified for FTN as

$$y(t) = \sqrt{Es}\sum_n x[n]\cdot h(t-n\alpha T) \qquad (2)$$

In the equation (2), $\sqrt{Es}$ represents the symbol energy, α is the factor which determines symbol time αT (equivalent to T0), where $\alpha < 1$. Lower the value of α, the more will be the data rate but at the same time error rate is increased. Thus it comes as a tradeoff between these two parameters. Unlike the ordinary linear modulation, FTN signaling system contains the pulses which are non orthogonal with respect to symbol time. The non orthogonal pulses used by FTN cause the sent symbols to be overlapped partially or fully depending upon the symbol interval T0. This gives rise to an unavoidable ISI, which causes a degradation of the system performance. To get the benefits of FTN, these ISI needs to be eliminated. This is achieved at the cost of higher receiver complexity. Different receiver processing techniques are implemented to simplify the process.

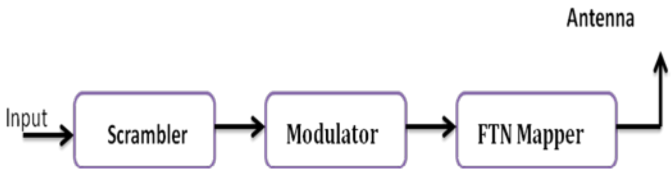
To sum up, FTN provides a benefit of high data rate at the background of same bit energy, spectrum usage and the error rate as of orthogonal transmission systems [2]. This factor is generating interest among the researchers to address the issue of bandwidth scarcity in the modern wireless communication systems. Increasing the data rate at the same time preserving the spectral efficiency is an important benefit of FTN. In the thesis work, study has been done to overcome the ISI that is likely to occur due to FTN. This is analyzed with the design of low complexity receiver structure.

## B.FTN PULSE SHAPING

Pulse shaping filters are necessary in communication systems to generate band-limited signals and reduce ISI in transmission. In FTN systems, pulse shaping filters are still required to limit the bandwidth of the signals. By breaking the Nyquist criterion, FTN signaling intentionally introduces ISI to achieve higher bandwidth efficiency. Different from the Nyquist signaling, the Mazo limit and FTN capacity are highly related to the power spectral density (PSD) of the FTN signal, which is determined by the shaping pulses when the input data are independent and identically distributed. Some typical shaping pulses have been introduced in [3], where the Mazo limits for binary FTN signaling with different RC family shaping pulses have been found. The relationship between the minimum distance and the Mazo limit for the uncoded and coded non-binary FTN signals with root raise-cosine (RRC) pulse has been exploited in [4]. It has been proved that the coding scheme is unable to improve the minimum distance but beneficial to the Mazo limit. In multicarrier FTN signaling, the performance of the Gaussian pulses and isotropic orthogonal transform algorithm(IOTA) pulses has been analyzed in[5],[6]. Moreover, according to [7], Gaussian pulse is the best candidate to increase the packed symbol number in both the time and frequency domains without BER performance loss and to reduce the side lobe power of linear modulation. Well designed pulses should also reduce the detection complexity. Therefore, the selection of shaping pulse affects the performance of the FTN systems and is vital to the FTN transmitter design.

## III. FTN TRANSMITTER

This section concentrates on the transmitter side of the system model and the signal processing of the transmitted waveform. The information signal is required to be modified in a way that it meets the requirements of signal transmission. Various signal processing techniques are implemented to introduce FTN to the transmitted signals. The transmitter block consists of different parts which are shown in figure 1



FTN MAPPER

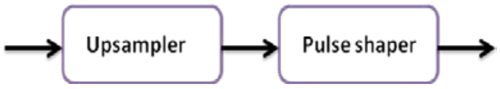


*Figure 1:FTN Transmitter*

At first, the uncoded signal is passed through scrambler. Then the Pulse amplitude modulation enables the information to be embedded in the amplitude of the carrier pulse. The modulation can be used for both baseband and pass band signals. Transmitted data is represented as a block of data. For baseband signal, it can be represented as

$$s(t) = \sum_n a_n g(t-nT), \quad n=1 to N \qquad (3)$$

where $a_n = \pm1,\pm2...$ denotes the amplitude carrying the signal information.

For FTN transmission systems, the time period for the signal transmission is reduced by certain factor. Equation (3) can therefore be deduced into

$$s(t) = \sum_n a_n g(t-n\alpha T), n=1 to N \qquad (4)$$

The signal for transmission thus generated,is sampled by the proper sampling procedures. Sampled signals are mapped with an upsampler of factor N and a pulse shaping filter h(t) which is symmetric. It has a unit energy. The effect of upsampling and pulse shaping filter is combinedly introduced as FTN mapping. For FTN transmission, $\alpha T < T$. In the equation (4), the term $\alpha T$ is the new time period instead of T which indicates that the time period is reduced. This implies that the pulses are no longer orthogonal. As a consequence, it produces an undesired ISI which is to be minimized. For creating a FTN scenario, it is upsampled by a factor K where $N < K$. This provides the FTN rate which is calculated by the ratio K/ N [1]. The term $\alpha$ which modifies the FTN time period is given by $\alpha = N/K < 1$. If these upsampling points are not estimated properly, they give rise to ISI. It indicates the distortion faced when the transmitted symbols overlap partially or totally thereby causing the degradation of the system by reducing the detection performance of receiver [2]. FTN symbols as it contains non-orthogonal signals are subjected to such ISI. Upsampling involves the addition of $(N - 1)$ zero samples between every sample of the input. This scales the time axis by factor N. In frequency domain analysis, this means the scaling of frequency axis by factor 1/N. FTN mapping involves upsampling of a modulated signal and its response after passing through the pulse shaping filter. The upsampled signal and the pulse filter generated response can be defined as,

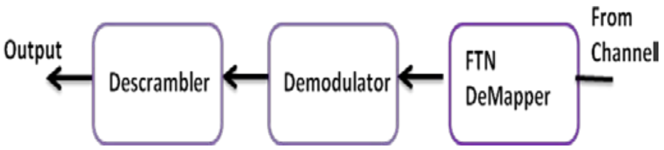
$$s(t) = \sum_k b_k h(t-k\alpha T), k=0 \text{ to } \infty \qquad (5)$$

$$v[n] = \begin{cases} b(n/N), & n = 0,N,2N \\ 0 & \text{otherwise} . \end{cases}$$

Here, v[n] is an upsampled signal response and s(t) is the signal response at an output of the pulse shaping filter used. Pulse shaping in the work is done using the raised cosine pulse as a pulse shaping filter. Pulse shaping filters are selected considering the requirement that they satisfy the Nyquist ISI criterion.

## IV. FTN RECEIVER

The receiver designing is discussed with the help of system model for the receiver section as shown in the Figure 2.



FTN DEMAPPER

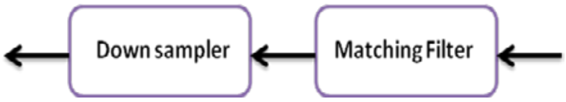


*Figure 2:FTN Receiver*

The received signal from the channel first faces the FTN demapping. This demapper provides symbol rate for the received signal. The received signal from the channel y(t) undergoes the demapping processing as shown in the Figure2. The result out of this demapping block is represented by r(t) which can be expressed as,

$$\begin{aligned} r(t) &= y(t)*h^*(-t) \\ &= (s(t) + \omega(t))*h^*(-t) \\ &= (\textstyle\sum_k b[k]h(t-k\alpha T))*h^*(-t) + \omega(t). \quad k=0 to \infty \qquad (6) \end{aligned}$$

The signal is sampled for every $\alpha T$. Using the same pulse shapes as that of the pulse shaping filter of the transmitter side, matched filtering $h^*(-t)$ is carried out for the received signal y(t). The resulting signal r(t) is then finally downsampled by the factor N, which is then passed to the channel demodulator and descrambler. FTN demapper consists of matched filter and downsampler. The sampled data is generated from the received continuous signal r(t). This is done in the matched filtering process. In reference to the upsampler used at the transmitter, receiver involves downsampler. Downsampling involves the removal of zero samples (i.e., scaling of time axis) which indicates the scaling of frequency axis by factor N.

## V. RESULTS AND DISCUSSION

Verilog codes for FTN Transceivers is written and simulated using Modelsim Altera Starter edition and implemented in Spartan 6 Evaluation Board.FTN transmitter section consists of scrambler, modulator, FTN mapper.FTN block consists of upsampler and pulse shaper. In scrambler input data is logically combined with random sequence which is generated by LFSR. The LFSR sequence is generated with the series of Flip Flops connected whose first two LSB is exor and given as feedback to the MSB. The generated output is xor with the input data bits. The scrambled data is modulated in 16 QAM with phase and magnitude values. The scrambled data is encoded in the QAM. The data is encoded with the values stored in the RAM, the input data values to QAM will serve as the address for the RAM to choose the equivalent magnitude and phase values. In the upsampler N-1 zeros are added in between samples. The major contribution of upsampler in the transmitter block is to create FTN scenario. It controls the delay of the system. The fine adjustment of this block controls interference in the signals. Pulse shaping is to make the transmitted signal better suited to its purpose typically by limiting the effective bandwidth of the transmission. Raised cosine filters are known for their ability to reduce the inter symbol interference of the signal. FTN receiver consists of matching filter, downsampler, demodulator and descrambler. This receiver block is used to retrieve the original data .The matching filter block is same as the pulse shaper at transmitter section. When a signal passes through these two identical filters, the effects of those filters are squared. This ultimately provides the total effect of raised cosine filter with an additional benefit of noise filtering at the receiver. The downsampler removes N-1 zeros between the samples. The downsampler must be downsampled at the same rate as of the upsampler. Decoded outputs are matched with RAM entries to produce the demodulated data. The demodulated output is XOR with the random sequence generated by LFSR to get back the original data. The same random sequence generated at the scrambler must be produced at the descrambler so as to retrieve the original data.

## A.BENCH SETUP

FTN Transmitter is operated with the Analog input and verified its working. The same analog input is given to the general transmitter without the FTN Mapper block and the results are compared. Figure 3 shows the block diagram for the experimental setup and figure 4 shows the hardware setup. At first general transmitter structure without FTN mapper is implemented and then FTN transmitter is implemented with the FTN mapper and their results are compared. Table 1 shows the comparison of general transmitter and FTN transmitter. To implement the structure with the analog inputs ,At first Analog signal must be converted into digital signal with help of the ADC, then the digital bits are passed into the FTN Transmitter block running in the FPGA. Then its converted back into analog signal with DAC. The Spartan 6 Evaluation board has 12 bit ADC and DAC. The analog signal of frequency in the range higher than MHZ can only be digitized in ADC so as to have a clear view on the CRO .The outputs of DAC is given to CRO and then comparison is done. The parameter bandwidth from the table is compared and it is found that FTN transmitter has low bandwidth and spectrally efficient .

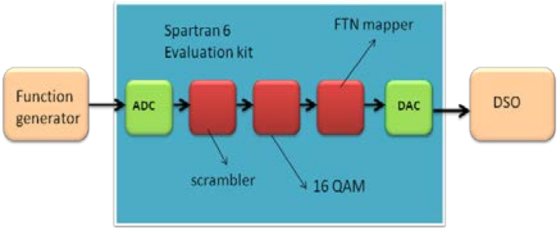


*Figure 3:Block diagram for Bench setup*

*Figure 4: Bench setup*

Table 1: Comparison

| Parameters | Without FTN Mapper | With FTN Mapper |
|---|---|---|
| Input Frequency | 1.24 MHZ | 1.24MHZ |
| $V_{PP}$ | 2.44 V | 2.44 V |
| Output Rise Time | 201.0ns | 219.6 ns |
| Bandwidth | 1.741MHZ | 1.593MHZ |

## VI. CONCLUSION

In this paper, we have provided an overview on FTN signaling and its basic principles have been discussed. Then the transmitter and receiver design has been presented. The bench setup for FTN was made and compares with general transmitter and found that FTN signals are spectrally efficient.

## REFERENCE

[1] El Hefnawy M. & Taoka H. (2013) Overview of Faster-than-Nyquist for future mobile communication systems.In: Vehicular Technology Conference(VTC Spring), 2013 IEEE 77th, IEEE, pp. 1–5.

[2] Anderson J.B., Rusek F. & Owall V. (2013) Faster-than-Nyquist signaling. Proceedings of the IEEE 101, pp. 1817–1830.
[3] A.D.LiverisandC.N.Georghiades,‘‘Exploiting faster-than-Nyquist signaling,IEEETrans.Commun.,vol.51,no.9,pp.1502–1511,Sep.2003.

[4] F. Rusek and J. B. Anderson, ‘‘Non binary and precoded faster than Nyquist signaling,’’ IEEE Trans. Commun., vol. 56, no. 5, pp. 808–817, May 2008.

[5] D. Dasalukunte, F. Rusek, and V. Öwall, ‘‘Multicarrier faster-thanNyquist transceivers: Hardware architecture and performance analysis,’’ IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 58, no. 4, pp. 827–838, Apr. 2011.

[6] F. Rusek and J. B. Anderson, ‘‘Multistream faster than Nyquist signaling,’’ IEEE Trans. Commun., vol. 57, no. 5, pp. 1329–1340, May 2009.

[7]J.B.AndersonandF.Rusek,‘‘Optimalsidelobesunderlinearan dfasterthan-Nyquist modulation,’’ in Proc. IEEE Int. Symp. Inf. Theory, Nice, France, Jun. 2007, pp. 2301–2304.

[8] A. Barbieri, D. Fertonani, and G. Colavolpe, ‘‘Time-frequency packing for linear modulations: Spectral efficiency and practical detection schemes,’’ IEEE Trans. Commun., vol. 57, no. 10, pp. 2951–2959, Oct. 2009.

[9] F. M. Han and X. D. Zhang, ‘‘Wireless multicarrier digital transmission via weyl-heisenberg frames over time-frequency dispersive channels,’’ IEEE Trans. Commun., vol. 57, no. 6, pp. 1721–1733, Jun. 2009.

[10] S. Mehmood, D. Dasalukunte, and V. Öwall, ‘‘Hardware architecture of IOTA pulse shaping filters for multicarrier systems,’’ IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 60, no. 3, pp. 733–742, Mar. 2013.