Dispersion Compensating Radio over Fiber (RoF) for 5G Radio Access Network

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1. INTRODUCTION

Next generation mobile system is the future mobile system that might integrates all other mobile generations specially Fourth Generation (4 G). Today’s conversation is centered on predicting what the mobile industry will look like in 2020 and beyond. Some countries have indicated that they would like to see 5G deployed even before 2020. The consensus emerging is that the industry must give enough time for technology breakthroughs that deserve the moniker 5G. In addition, there is a consensus that because Long-Term Evolution (LTE) and LTE-Advanced are presently being deployed, there is considerable life left in 4G. In fact, the LTE family of technologies should remain viable through at least 2020 because they will continue to evolve and advance in terms of higher speeds and greater capacity. Carrier Aggregation (CA), small cell enhancements and device-to-device signaling are just some of the examples of how LTE is advancing (4G Americas, white paper, 2015).

Many researches has been introduced each with a certain part of the system, for example, some of them about the radio access network,
others about the channel assignment, cell planning, …etc. the questions are; when will 5G be deployed? What will characterize networks in 2020 and beyond? What are the likely solutions and technologies that will come in to play? These are some questions currently being discussed among operators, the supplier community, research institutions, standards bodies, trade organizations and governments (4G Americas, white paper, 2015).

Examination of 5G requirements and solutions is basically an exercise in planning a network evolution plan that spans six to seven years. While past generations have been identified by a major new technology step, such as the definition of a new air interface, the expectation is that 5G will be approached from an end-to-end system perspective and include major technology steps both in the radio access network and core network. These steps can be evolutionary or revolutionary by introducing a completely new concept (4G Americas, white paper, 2015).

In this paper, the radio access network part has been designed with a new proposed topology using Radio over Fiber (RoF) system, challenges of RoF like dispersion has been studied that how can be minimized and then compensated for the proposed radio access network, finally, some test and examined results presented with conclusions.

2. 5G MOBILE SYSTEM

Mobile telecommunication system grown very fast motivating the companies to plan continuously and work from first generation until fourth generation, many companies in this field planned and started their scenarios toward fifth generation (5G) mobile, this is because of the need of higher data rate transmission and wireless system radio network (Wei Xiang , et. Al, 2017). The fifth-generation (5G) mobile communications system will emerge to meet new and unprecedented demands beyond the capability of previous generations of systems, 5G will support a large variety of use cases which are emerging now or will emerge in the future (Wei Xiang , et. Al, 2017). The Radio Access Network (RAN) design for the next generation, Radio Access Technologies (RAT) shall be designed to fulfill many requirements, for example the RAN architecture shall support tight interworking between the new RAT and LTE, considering high performing inter-RAT mobility and aggregation of data flows via at least dual connectivity between LTE and new RAT. This shall be supported for both collocated and non-collocated site deployments, the RAN architecture shall support connectivity through multiple transmission points, either collocated or non-collocated, the RAN architecture shall enable the separation of control plane signaling and user plane data from different sites, RAN-CN interfaces and RAN internal interfaces (both between new RAT logical nodes/functions and between new RAT and LTE logical nodes/functions) shall be open for multi-vendor interoperability, and the RAN architecture shall support operator-controlled side link (device-to-device) operation, both in coverage and out of coverage. 5G networks are expected to hugely increase network densification, The large number of small cells, together with the growing coexistence of multiple radio access technologies (RATs) like global system for mobile communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), etc., leads to an increasing complexity in the Operations, Administration, and Management (OAM) of cellular networks (Sergio Fortes, et. al, 2016).

3. RADIO OVER FIBER (RoF) SYSTEM

Radio over Fiber (RoF) is a promising technology for short range transmission applications within multimode optical fiber, radio over fiber (RoF) system is an analog link transmitting modulated Radio Frequency (RF) signals. It serves to transmit the RF signals down and uplink, i.e. to and from Central Stations (CS) to Base Stations (BS) called also radio ports. RF modulation in most cases is digital in any usual form, such as Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM), Trellis Coded Modulation (TCM). Moreover, RoF also called Fiber to the air, which is the one emerging technology applicable in high capacity, broadband millimeter-wave access systems.
In this system, the costs of BSs will be decreased because most of signal processing including coding, multiplexing, RF generation and modulation, etc. is made in CSs rather than in the BSs. The signal to and from these is transmitted in the optical band, via a fiber optic network. The design of BSs really be simple, in the simplest case a BS doesn’t comprise else than optical-to-electrical (O/E) and electrical-to-optical (E/O) converters, an antenna and some microwave circuitry (two amplifiers and a diplexer).

In the last decade or so significant research work was done in this field with significant results, the number of publications is abundant, some problems to be solved and there will be some benefits in the new architecture using RoF, but there are still special problems like resource management, channel allocation, interference, data rate improvement. RoF technology allows a micro cellular network system to be implemented by using a fiber-fed distribution antenna network.

Simplified RoF system block diagram is given in Figure 1. The RF part is between the input signal and Electrical to Optical conversion (E/O), and the received signal with that in Optical to Electrical Conversion (O/E).

Optical fiber system like other communication channels has many impairments for example, attenuation, linear and non linear scattering losses, fiber bend loss, and dispersion, this work focused on dispersion effect because it has a great effect on the data rate as given in equation (1) (John M. Senior, 2009):

\[
\text{Data rate} = \frac{0.2}{\sigma_T}
\]  

(1)

Where, \(\sigma_T\) is the total dispersion given in equation (2) with chromatic and modal dispersion:

\[
\sigma_T = (\sigma_c^2 + \sigma_m^2)^{1/2}
\]  

(2)

Where,

\(\sigma_c\) is the chromatic dispersion, \(\sigma_m\) is the modal dispersion

And the chromatic dispersion is given in equation (3) while the modal dispersion depends on the fiber type step index or graded index, equation (4) is the modal dispersion for the step index and (5) for the graded index fiber:

\[
\sigma_m \approx (\sigma_\lambda L/c)\frac{\lambda^2 n_2}{d\lambda^2}
\]  

(3)

Where, \(\sigma_m\) is the material dispersion, \(\sigma_\lambda\) is the spectral width of the laser, \(L\) is the fiber length, \(\lambda\) is the wavelength, and \(n_2\) is the core refractive index.

\[
\sigma_\epsilon = (L n_2 \Delta) / (3.4 c) = (L (NA)^2) / (6.8 c)
\]  

(4)
Where, $\sigma_s$ is the modal dispersion for step index fiber, $\Delta$ is relative refractive index difference, $NA$ is the numerical aperture and $c$ is the velocity of light = $3 \times 10^8$

\[
\sigma_g = \frac{(Ln_1 \Delta^2)}{34c} \tag{5}
\]

Where, $\sigma_g$ is modal dispersion in graded fiber

4. DESIGN AND METHODOLOGY

The proposed topology for the 5G Radio Access Network (RAN) in this paper is that the connections between Base Transceiver Stations (BTS) and Central Base Station (CBS) will be using RoF instead of microwave (MA Zheng et al, 2015). This is because of many disadvantages of microwave link like maintenance, interference, atmosphere effects, etc. therefore, RoF will be the alternative for the microwave link because these disadvantages will be solved by RoF, the topology is mesh topology because in this topology an interrupt in the link will not affect the data transmission because there will be other path links even as a disadvantage of mesh topology the cost of the fiber used. All the Base Transceiver Stations (BTS) will be connected via RoF to Columbia Broadcasting System (CBS) instead of many Base Station Controller (BSC) like that used in 3G or GSM or even 4G mobile systems, this will facilitate the cell planning procedure also and channel assignment.

After the design of RAN is proposed, the dispersion effect has been studied, first, using equations (1-5), the optimized values and relations between dispersion and other fiber parameters has been obtained and presented using MATLAB package, and then the data rate versus fiber length this is because of the connection between each BTs and CBS depends on the fiber length.

Figure 2 shows the relation between data rate and the fiber length using multimode graded index fiber optics because dispersion affecting on them more than single mode with different relative refractive index differences (Delta). It is shown that fiber length is until about 6km, but for 4 G the coverage radius is about 2km and for 5 G about 1 km because of higher frequency bandwidth. Thus, relative refractive index difference must be less than 0.04 for a higher data rate.

![Figure 2: Data Rate Versus Fiber Length for the Graded Index Fiber.](image)

Figure 3 shows the relationship between fiber length and data rate with different numerical apertures (Na), using multimode step index fiber optics, it is found that for higher data rate and fiber length about 2km for 4 G and about 5 G, numerical aperture must be less than 0.028.

![Figure 3: Data Rate Versus Fiber Length for Step Index Fiber.](image)
Figure 4 shows the relationship between data rate and relative refractive index difference (Delta) for different cluster sizes (N) using multimode step index fiber optics. It is shown that without clustering (N=1), the data rate is higher, but this causes higher Co-channel interference (CCI) and Adjacent Channel Interference (ACI), and hence Signal to Interference Ratio (SIR) will be decreased. Therefore, N=3 and N=7 clustering would be more optimal because these cluster sizes have less CCI and ACI specially where N = 7 during cell planning procedure. Using the cluster size N=4, the distribution for the base stations will not be uniform, and using N=7, the base station numbers will be increased, but carriers will be decreased. Again, using N=3, the number of base stations decreased, but the carrier frequencies used increased. Thus the two cluster sizes N=3 and N=7 are used. For graded index multimode fiber, the relative refractive index difference must be less than 0.0004 for a higher data rate, as shown in Figure 4.

Figure 4 : Data Rate Versus Relative Refractive Index Difference for Step Index Fiber.

Next step after the optimization, using Opti System software the special software for the optical design, the design of the RAN with compensating dispersion using Fiber Bragg Grating (FBG), and the Dispersion Compensating Fiber (DCF) to minimize the dispersion and then higher data rate, In addition the optical amplifier Erbium Doped Fiber Amplifier (EDFA) to attenuation compensation by amplifying the signal and increasing the signal quality by minimizing the dispersion has been used as shown in Figures 6-8. Figure 6 is the basic dispersion compensation using FBG for each BTs. Considered by user defined bit sequence and O/E by RoF.
5. RESULTS

Many RAN designs and topologies has been presented by many researchers, in this paper after the design of a new RAN topology has been presented using RoF, the main impairments in optical system which is the dispersion is studied and the optimum level of dispersion and then the maximum data rate for the RAN obtained. Figure 10 shows the power spectrum of the transmitted signal after WDM from eight BTSs, the power is about -7dBm and the frequency is 193.1 THz – 193.8 THz spacing 0.1 THz. Figure 11 shows the power spectrum of the received signal by the BTSs after 2 km length of the fiber which is the distance between each two neighbor BTSs, each with 1 km radius. Figure 12 is the received signal after the use of loop control (2 loops) and finally, Figure 13 is the received signal after the FBG and the EDFA which will be demultiplexed by WDM/DEMUX then to each BTs, thus the received signal by each BTs
will be dispersion compensated as well as attenuation compensated with higher signal quality.

Figure 10: Power spectrum of the transmitting signal with eight WDM BTSs

Figure 11: Power spectrum of the received signal by eight BTSs

Figure 12: Power spectrum of the received signal from the loop control

Figure 13: Power spectrum of the received signal from the FBG and the EDFA and input to WDM/DEMUX

Figure 14 is power spectrum of the input signal to the proposed RAN from each BTS, it is shown that the duration of the signal is small.
Figure 14: Power spectrum of the input signal to the proposed RAN from each BTs

Figure 15 is the power spectrum of the received signal by each BTs before dispersion compensating (without dispersion compensation). It is shown that the duration of each signal is broadened caused by dispersion which affects the data rate and causes Inter Symbol Interference (ISI), when all the signals received together by the BTSs, with the use of the proposed work in this paper, this pulse broadening will be minimized and then the dispersion effect will be minimized, ISI will be decreased, then the data rate will be increased and the signal quality will be increased as shown in Figure 16, finally, Figure 17 shows the power spectrum of the three signals together for the purpose of comparison of the transmitting, receiving signal with and without dispersion compensation.

4. CONCLUSIONS
In this paper a new proposed radio access network for 5G mobile system has been presented, radio over fiber system proposed to be the link between base stations and a central station with a mesh topology. The main impairment of fiber system which is dispersion has been studied with the main methods of this effect compensation. A new model proposed radio access network with minimum dispersion has been presented, the new model is a combination of more than one method of dispersion compensation like dispersion compensation fiber, fiber brag grating and opt Grating linear chirp and anodization, it shown in results that with the use of the proposed model the pulse broadening and then the dispersion will with minimum level which leads to higher data rate and signal quality, it is a contribution in the field of 5G mobile system architecture and radio access network.

REFERENCES

4G Americas, “5G Technology Evolution Recommendations”, white paper, October, 2015

Wei Xiang · Kan Zheng Xuemin (Sherman) Shen, “5G Mobile Communications”, Springer, Springer International Publishing Switzerland 2017.

Sergio Fortes*, Raquel Barco* and Alejandro Aguilar-Garcia, “Location-based distributed sleeping cell detection and root cause analysis for 5G ultra-dense networks”, Fortes et al. EURASIP Journal on Wireless Communications and Networking (2016) 2016:149.

John M. Senior, “Optical Fiber Communications, Principles and Practice”, book, third edition, Pearson Prentice Hall, 2009.

MA Zheng1, ZHANG ZhengQuan1*, DING ZhiGuo2, FAN PingZhi1 & LI HengChao1, “Key techniques for 5G wireless communications: network architecture, physical layer, and MAC layer perspectives”, Science China Press and Springer-Verlag Berlin Heidelberg 2015, April 2015 Vol. 58.

Ashima Rana, “INVESTIGATION ON RADIO OVER FIBER NETWORKS USING VARIOUS MODULATION SCHEMES”, M.Sc. thesis, Electronics and Communication Engineering, Thapar University, Patiala, 2016.

Vimala Reddy and Lochan Jolly, “Simulation and Analysis of Radio over Fiber (RoF) Systems using Frequency Up-Conversion Technique”, International Journal of Computer Applications (0975 – 8887) Volume 133 – No.12, January 2016.

Vikas Kumar Pandey, Sanjeev Gupta, and Bharti Chaurasiya, “Radio-Over-Fiber (ROF) Technology With WDM PON System”, International Journal of Innovation and Scientific Research ISSN2351-8014Vol.7No.2Aug.2014, pp.78-84 © 2014 Innovative Space of Scientific Research Journals.

Jonathan Rodriguez, “Fundamentals of 5G mobile networks”, 2015 John Wiley & Sons, Ltd.

Shuvodip Das, Ebad Zahir, “Performance Enhancement of Radio over Multimode Fiber System using Fiber Bragg Grating for Micro and Pico Cell Applications”, International Journal of Scientific & Engineering Research, Volume 5, Issue 7, July-2014.

Matteo Fiorani, Björn Skubic, Jonas Mårtensson, Luca Valcarenghi, Piero Castoldi, Lena Wosinska, and Paolo Monti, “On the design of 5G transport networks”, Photon Netw Commun (2015) 30:403–415, CrossMark, Springer.

Sanddeep Singh, Neeraj Gupta, Ravi Prakash Shukla, and Anamika Sharma, “Simulation of full duplex data transmission in ROF system using Optisystem”, International Journal of Electronics and Computer Science Engineering.

Arya Mohan and Anisha A. P, “Performance Comparison of Radio over Fiber System Using WDM and OADM with Various Digital Modulation Formats”, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2013), Volume 4 Issue 2, February 2015.