Radio over fiber system architecture: a boon to meet future energy and pollution challenges

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Access networks consume the major part of overall telecom network energy. It is necessary to evolve energy-efficient network architecture to reduce their energy consumption and also to reduce the overall electromagnetic pollution induced environmental hazards. The energy consumed by base stations (BS) is a major chunk of the total energy consumption in a cellular network and hence reducing the number of base stations has a direct impact on energy consumption. One obvious way to make the cellular networks more power efficient and sustain high capacity is by decreasing the propagation distance between mobile nodes and the base station, hence reducing the transmission power and eliminating the power amplifier (PA) requirements. The concept of Radio over Fiber connected Small-Cell Networks (SCN) architecture with dense deployment of self-organizing, low cost, low power base stations is proposed to meet a true green mobile network. The link power budget for WCDMA and HiPERLAN2 systems were carried out and validated with the support of digitized RoF link architecture for 2.4 GHz and 5.0 GHz RF band. The power budget concludes that a very low power of 3.75dBm is sufficient to establish a link between mobile user and remote antenna unit, and hence endorse the green concept.

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1. Introduction

The explosive growth in data traffic, the upgrade to higher-capacity technologies such as High Speed Packet Access (HSPA), Evolved HSPA (HSPA+), or Long Term Evolution (LTE), and the backhaul requirements for new small cell sites rapidly increase their backhaul capacity requirements. Consumer quality of experience can be enhanced by ‘peppering’ small cells in general areas of high demand, making the most of sites that can be easily backhauled with high capacity fiber [1]. Capacity enhancement can be considered as a way of increasing the number of people that can have a given level of broadband experience in an area during the busy times. Fiber provides a very high capacity and low latency connection, fiber is likely to be an effective way of connecting up a continuously evolving set of outdoor small cells mounted on street furniture [1, 5].

The phenomenal growth of wireless connectivity is made possible at the expense of considerable energy consumption, which in turn adds to carbon dioxide (CO_2) emission and global warming problems [2]. Information and communication technology (ICT) contribute around 2% of the total carbon emissions of which mobile networks represent 0.2%. Vodafone, one of the largest mobile service providers has reported[3],that its energy (gas and electricity) consumption in the United Kingdom comprised 228Gwh at its base station units, 112GWh used by other network equipment and 57Gwh for its offices and retail spaces for the 2007–2008 operation year. This level of energy consumption powered over 12,000 base stations, as well as 8 major offices and 347 retail stores [5]. More than 50% of the energy consumption is directly attributed to base station equipment and 30% more to mobiles switching and core transmission equipment as depicted in Fig. 1(a).

It is clear that the operation of an access network, and more specifically base stations , and within a base station, the power amplifier (PA) and feeder circuits (Figure 1(b))significantly outweigh other entities in the overall power consumption. The essential parts of a BS are radio, baseband and feeder. Out of these three, radio consumes more than 80% of a BS’s energy requirement, of which power amplifier (PA) consumes almost 65%. Shockingly, 80-90% of that is wasted as heat in the PA, and which in turn requires air-conditioners, adding even more to the energy costs. Modern BSs are terribly inefficient because of their need for PA linearity.

With the advent of data intensive cellular standards, power-consumption for each base station can increase up to 1,400 watts and energy costs per base station can reach to $ 3,200 per annum with a carbon footprint of 11 tons of CO_2. A surge in wireless network power consumption is directly translated into increasing CO_2 emission. It is therefore crucial to address the energy efficiency of current and next-generation wireless networks [5].

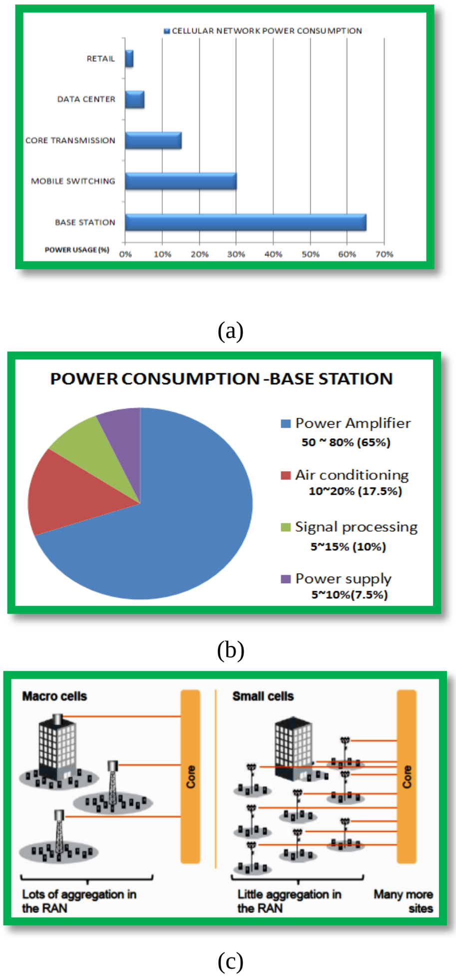


Fig. 1. (a) Power consumption of a typical wireless cellular network (b) Breakdown of power consumption in a typical base station [5, 6] (c) Deployment of small cell Networks-SCN [1].

Future broadband access networks have to be bimodal, exploiting the high capacity and low power consumption of passive optical fiber infrastructures and the ubiquitous nature and mobility support of wireless networks, giving credence to radio over fiber (RoF) access networks. Since access networks consume the major part of overall telecom network energy, it is necessary to evolve energy-efficient network architecture to reduce their energy consumption [4].

The concept of small-cell networks (SCN) depicts a very dense deployment of self-organizing, low cost, low power base stations with self-optimization and self-healing mechanisms (Fig. 1c) [5, 7]. Umbrella cells would be needed to ensure area coverage, while most of the traffic is carried by a large number of small cells. Cellular network deployment solutions based on small cells such as micro, pico and femto cells are very promising in that aspect being more power efficient and providing broadband coverage. However the problem of keeping a large number of densely deployed small cells and the umbrella cells powered up all the time even under lighter load conditions may tend to reduce the energy efficiency. In order to exploit the spatial and temporal fluctuations of the traffic load, the concept of cell zooming can be deployed wherein, the cell sizes are adaptively adjusted based on the traffic load, user requirements and channel conditions, [5, 8].

Under low traffic or when traffic is spatially concentrated at specific locations, a fewer number of cells can zoom out to provide coverage and the rest of the base stations can be switched off. This can give rise to significant power savings. However, this saving comes at some cost: there may be some coverage holes and more importantly, since a cell zoom out means larger coverage area and larger transmit power, the uplink transmission power of mobiles at zoomed cell edges also increases. This may imply a higher electromagnetic field exposure to the mobile user and his immediate neighbors as well as a larger pollution closer to the base station tower [9]. This is depicted in Fig. 2b and 2c. Recently, all over the world, people have been debating about associated health risk due to radiation from cell phone and base stations. Hence architectures addressing, energy efficiency along with reduced electromagnetic pollution become very relevant.

	Small Cell	Macro Cell
Cost of BTS	$3K-$6K	$30K - $60K
Average	$4,500	$45,000
Site Acquisition		
Collocation	$5,000	$50,000
New Site	$15,000	$150,000
Microwave Backhaul	$4,000	$4,000
Monthly Site Rental	$200	$800
Site Maintenance /month	$50	$200

(a)

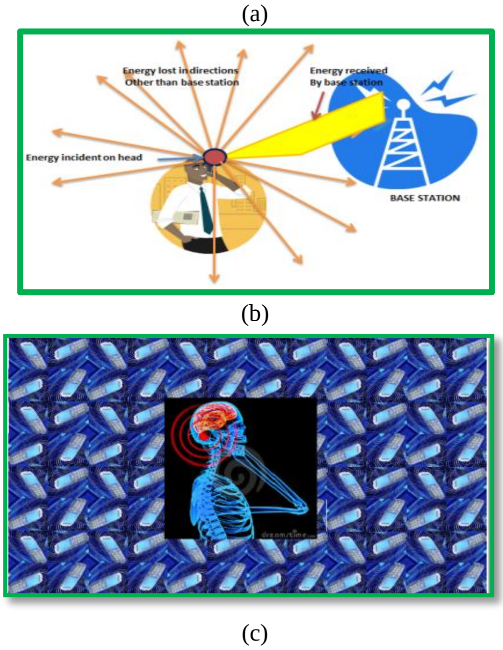


Fig. 2. (a) Cost comparison of a typical macro cell and small (b) Electromagnetic spreading [9, 10] (c) Electromagnetic cloud due to multiple users in the Vicinity [9].

The architectural solution based on small cell networks (SCN) and cell zooming with a fiber backhaul reaching the closest point of contact with the mobile user can address this balance between energy efficiency and electromagnetic pollution. A virtual zooming over fiber backhaul along with the small cell networks keeps the transmitted power low over the wireless space thereby eliminating the usage of power hungry power amplifiers (PA).

In this paper we investigate the feasibility and the green aspects of a probable RoF based architecture for the transmission of high data rate over a cellular network. The RoF based cellular scenario and the link configurations considered are discussed in section 2. The link budget estimation for WCDMA RoF systems and HiperLAN2 RoF systems are presented in section 3. The digitized RoF link details and the parameters considered for the simulation are presented in section 4 and the results obtained are discussed in section 5. The conclusions and inferences made are listed in section 6.

2. Radio over fiber based cellular scenario

The generic architecture of a Radio over fiber (RoF) system is shown in Fig. 3 [12]. A fiber radio network differs from a traditional fiber to the home (FTTH) access network in that the transported data is at a wireless frequency. The radio-over-fiber (RoF) technology uses an optical fiber link to distribute RF signals from a central base station (CBS) to remote antenna units (RAUs or low power pico base station) and vice versa. RoF makes it possible to centralize the signal processing functions such as frequency up-conversion, carrier modulation and multiplexing, in one shared location (head end-CBS) and then use optical fiber to distribute the RF signals to the RAUs. Hence RAUs are simplified significantly, as they only need to perform optoelectronic conversion (O/E & E/O) and if necessary amplification functions [13, 14].

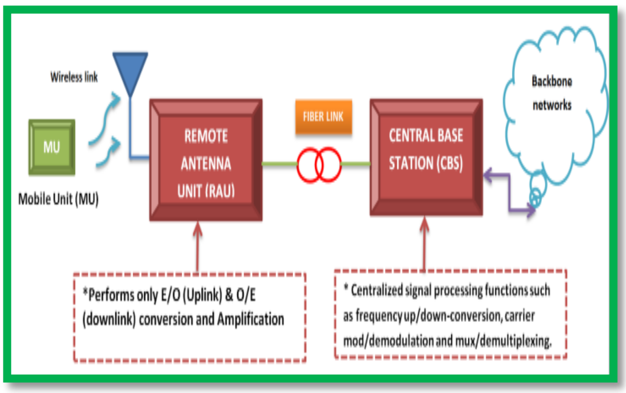
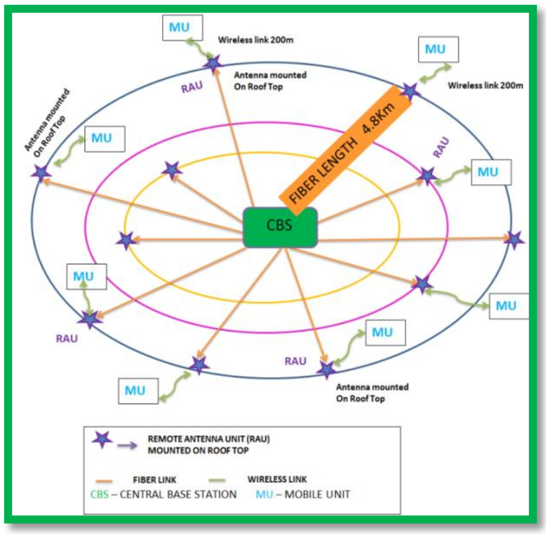


Fig. 3. Radio over Fiber (RoF) system for cellular access.

The radio over fiber (RoF) technique can be effectively modified to provide transparent transmission of the wireless signals from multiple service providers in dense urban areas. A single mode fiber (SMF) that spans a distance of 4.8 km is used. This fiber link is provided between the central base station (CBS) and the remote antenna units (RAU). A wireless link of 200m exists between RAU and MU. In the upstream direction, radio signals generated at the customer site are received by the RAU, up converted to optical domain and are directed to the CBS for further processing. The basic architecture and the dense urban small cell deployment option are shown in Fig. 4a &b.



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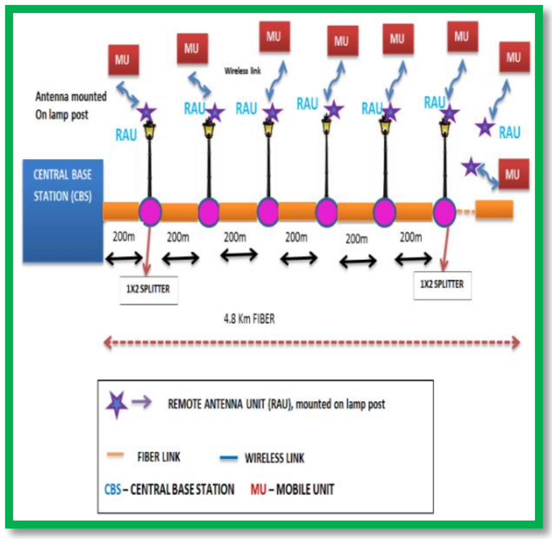


(b)

Fig. 4. (a)Radio over Fiber (RoF) Scenario in Cellular network (b) Practical RoF Link for power budget calculation.

The different service providers like Vodafone, Airtel, DoCoMo, and Uninor, etc. can utilize the integrated infrastructure of the remote antenna unit (RAU). In the proposed architecture, RAUs can be located below roof level like public buildings or typically mounted on items of street furniture such as lamp-posts [15] as shown in Fig. 4b. Coverage is essentially Omni-directional. In the current scenario, RAUs are spaced around 200 m apart, which is a compromise between high deployment cost and the need to provide high capacity (i.e., a high number of users and a high average data rate per user). Target radio range is 10 m to 200m which provides some coverage overlap at the cell edges.

3. Radio over fiber link power budget

The radio over fiber link length of 5 km is considered for estimating the link power budget. A single mode fiber that spans a distance of 4.8 km is used. This fiber link is provided between the CBS and the RAUs. The wireless link of 200m exists between RAU and MU. The possible implementation of RoF link is shown in Fig.4b. In a practical RoF link, splitters are used and they introduce various types of losses like insertion loss (IL), polarization dependent loss (PDL), etc. Planar light circuit splitters are fully passive optical branching devices that exhibit uniform signal splitting for the most advanced optical networks. As radio waves propagate in free space, power falls off as the square of range. For a doubling of range, power reaching a receiver antenna is reduced by a factor of four. This effect is due to the spreading of the radio waves as they propagate, and the loss can be calculated.

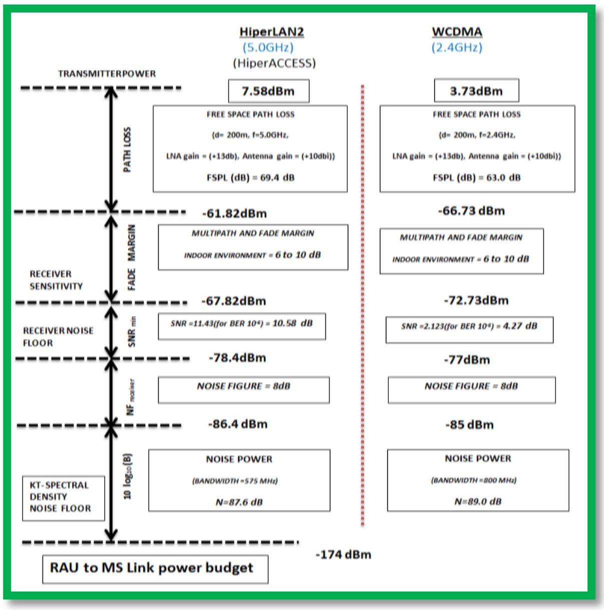
Free space path loss (FSPL) =20 $\log_{10}$ (4πd/λ) (1)

Where, **f** = frequency (Hz), **d** = the distance between Rx and Tx, **λ** = free space wavelength = c/f, **c** = speed of light (3×10^8 m/s)

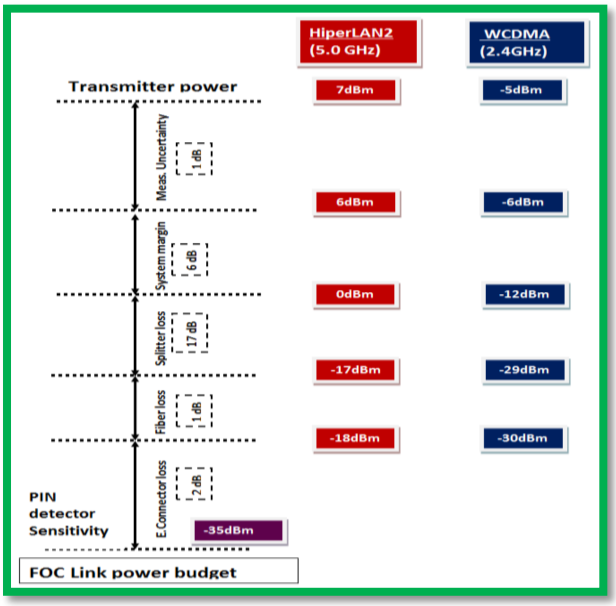
Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB) (2)

The equation (2) can be used to calculate the required transmitted power, when receiver sensitivity, gains and losses are known. Gains are provided by power amplifiers, transmitting antenna and receiving antenna. Losses are due to free space path loss, multipath propagation, loss provided by feeder transmission lines etc.

Link power budget analysis for the entire RoF link is undertaken. It is carried out in two parts- fiber optic link budget and wireless budget, for Hiperlan2 and WCDMA signals. Fiber optic link power budget, taking into account all losses is shown in Fig. 5a. The first column depicts values for a Hiperlan2 signal (575 MHz BW @ 5 GHz carrier) and the second column shows values for a WCDMA signal (800 MHz @ 2.4 GHz carrier). The large signal bandwidths (BW) are considered to depict an integrated multiple operator / multiple services scenario. The wireless power budget from RAU to MU for both Hiperlan2 and WCDMA signal transmissions in that order is shown in Fig. 5b.



(a)



(b)

Fig. 5. Link power budget (a) Fiber Optical link (b) Wireless link.

A conventional wireless link with a 5km span is as shown in Fig.6. The total area covered is 78.57 sq. km (**Area=πr^2=π***5^2=78.57sq.km) .In order to cover the same area using RoF links and RAUs with 200 m spacing, we would require roughly 1936 RAUs (for 1 sq.km nearly 25 RAUs are needed to provide sufficient coverage). For a conventional wireless link, Free Space Path Loss (FSPL) for Hiperlan2 system and WCDMA system is 120.403 dB and 114.0336 dB respectively using the equation (1), whereas for the RAU to mobile the path loss for Hiperlan2 system and WCDMA system is 69.4 dB and 63 dB, respectively (Fig. 5 b).

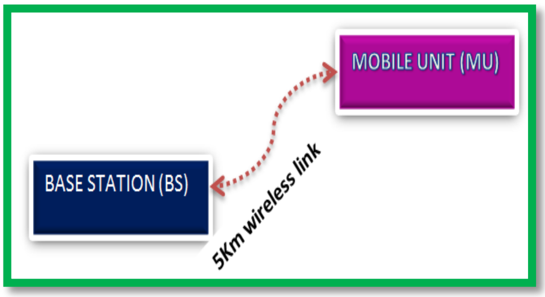


Fig. 6. Conventional BS-MU wireless link.

Table 1. Minimum transmit power requirements.

System type / Link type	HiperLAN2 (5.0 GHz) (HiperACCESS)	WCDMA (2.4GHz)
RoF link	5.73mW (7.58dBm)	2.36mW (3.73dBm)
Conventional Wireless link	721.1W (58.58dBm)	298.5W (54.75dBm)

In the conventional wireless link, power required to be transmitted by the base station for Hiperlan2 system is 58.58dBm and WCDMA system is 54.75dBm as shown in Table 1. These can be considered to be the transmitted power requirements equivalent to 2875 (575 MHz/200 KHz) and 4000 (800 MHz/200KHz) GSM channels, respectively for the two systems. As per the power consumption model for GSM base stations [17], the total power consumed in the conventional base station and the RAUs to support the above signals can be estimated. These are shown in Table 2 and Table 3 for the conventional wireless base station link and the RAU based RoF scenario. The power consumption of the fiber optic link currently assumed to be operating at a single wavelength can be considered to be relatively small. Further the power amplifiers and the climate control setup may not be needed at the RAUs due to the smaller transmitter power [18] requirements. The minimum power that needs to be transmitted by the RAU for RoF link and conventional wireless base station are calculated and shown in Table 1.

The following losses based on [17, 18, and 19] are considered:

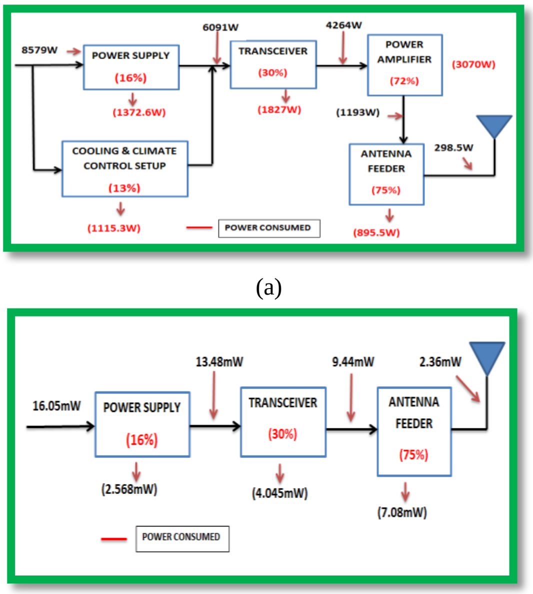
Loss due to Climate Control Setup ~ 13% of input power
Loss in the Power Supply unit ~ 16% of input power
Loss during TXR idle mode ~ 30% of PS output
Loss in Power Amplifier ~ 72% of TXR power under TX mode
Loss in the Feeder setup ~ 75% of Power Amplifier output

Table 2. Power consumption of conventional wireless Base Station (BS).

Power at different stages	HiperLAN2 system (HiperACCESS)	WCDMA system
Power sent over air	721.1W (58.58dBm)	298.5W (54.75dBm)
Power at Feeder input	2886W	1193W
Power at amplifier input	10307W	4264W
Power input to Transceiver	14725W	6091W
Grid power to power supply unit and climate control unit	20.738kW	8.578kW
No. of BSs	1	1
Total power consumption	20.738kW	8.578kW
Useful power / Total power consumed (%)	3.5%	3.5%

Table 3. Power consumption of RAUs based RoF link.

Power at different stages	HiperLAN2 system (HiperACCESS)	WCDMA system
Power sent over air	5.73mW (7.58dBm)	2.36mW (3.73dBm)
Power at Feeder input	22.91mW	9.44mW
Power input to Transceiver	32.73mW	13.48mW
Grid power to power supply unit	38.964mW	16.048mW
No. of RAUs	1936	1936
Power consumption by all RAUs	75.434W	31.069W
Total power consumption including climate control unit	86.75 W	35.728W
Total useful transmitted power	11.093W	4.569W
Useful power / Total power consumed (%)	12.8%	12.8%



(a)

(b)

Fig. 7. Power consumption of (a) conventional wireless base station – WCDMA (b) RAUs based RoF link – WCDMA.

The power consumption at each stage of the conventional wireless link and RoF link for WCDMA system is presented in Fig. 7a and Fig. 7b. In the case of the conventional wireless link only one base station is required; however the total power consumption is significantly high compared to the RoF link with 1936 RAUs. By using RoF link with RAUs, the power consumption can be reduced by almost 99%, at the same time increase the percentage of useful power, as seen from the tabled results (Table 3 and Fig. 7b). Further, since the radiated power is much smaller, the ensuing electromagnetic pollution will also be less. This is a significant motivation to adopt RoF based wireless access, though the deployment cost may show some increase.

4. Digitized radio over fiber architecture (Uplink configuration)

The previous section highlights the significance of adopting the fiber backbone and taking it as close to the end user as possible in a cellular mobile communication system. The objective in this section is to analyze the performance of such a link. An uplink configuration of RoF system with digitized fiber link as depicted in Fig.8 is considered [20]. The link parameters considered in the simulation are listed in Table 4.

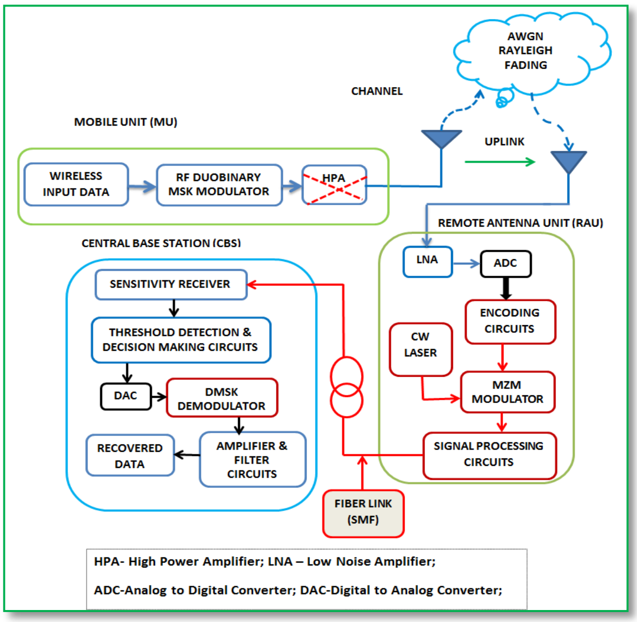


Fig. 8. Digitized radio over fiber - uplink configuration.

Table 4. Simulation parameters.

PARAMETERS	VALUE
Input data rate (Integrated value)	1Gbps
Modulator type	Duo-binary MSK
RF band frequency	2.4GHz,5.0GHz
Transmitter antenna gain (Mobile unit)	+10dBi
EIRP (UPLINK)	-30dBm to +33dBm
Channel type	AWGN (RAYLEIGH FADING)
Receiver antenna gain (RAU)	+10dBi
Receiver sensitivity (RAU)	-90dBm
LNA gain	12dB(2.4GHz),15dB(5GHz)
LNA Noise Figure	1.9dB(2.4GHz),3.0dB(5GHz)
ADC threshold	2^*e^{-005}
Vπ value of MZM modulator	5V
Center emission frequency of CW LASER	193.414THz(1550nm)
CW LASER power	-10 to +10 dBm
FWHM line width of LASER	10 MHz
Fiber length	5 Km
Fiber loss	0.2 dB/Km
Dispersion at the reference frequency(D)	-16 ps /nm/Km
Non linear refractive index	$2.5e^{-20}$
Total compensating dispersion at ref. freq	-80 ps/nm
Receiver sensitivity (PIN)	-33.92248 dBm
Receiver responsivity(R)	1.0 A/W

Mathematical formulation:

The mobile user data at a rate of 1.0Gbps (could be multiplexed rate) generated by PRBS source is modulated using duo-binary MSK and up-converted to a frequency of 2.4 GHz to depict the RF signal. The period length of the pseudorandom sequence generated by a PRBS source is 2^D-1 bits, where D is the degree set by the parameter [23]

$$D = \frac{\log_{10}(N_b + 1)}{\log_{10} 2} \quad (3)$$

Where, $N_b = \text{int}(T_{sim} * R_b)$ T_{sim} - Total simulated time span, R_b – actual bit rate.

The modulated RF signal generated at the Mobile Unit (MU) is directly transmitted using an antenna of gain 10 dBi. The EIRP (Effective Isotropic Radiated Power) of the MU is assumed to vary from -30dBm to +33dbm (0.001mW to 2W). High power amplifier (HPA) is not necessary to cover the micro cell range of distance between mobile unit (MU) and remote antenna unit (RAU). The distance between MU and RAU is assumed to vary from 50 m to 200 m. In the simulation scenario varying distance between MU and RAU is realized by changing the equivalent propagation loss which is estimated using RF link budget calculator [21]. The ideal free space loss (FSPL) model is assumed which can be calculated as

$$FSPL = 20 log_{10}\left(\frac{4\pi D}{\lambda}\right) (or)\ FSPL = 20 log_{10}\left(\frac{4\pi Df}{c}\right) \quad (4)$$

The Channel is assumed to be a Rayleigh fading channel. The Rayleigh fading channel responds very well up to the transmitting power of -25dBm from MU. The shadowing effect of the channel between MU and RAU is modeled with a log normal distribution [23] having pdf as follows

$$f(x)=exp\left(\frac{-(x-mean)^2}{2\sigma^2}\right) \quad (5)$$

Where ' σ ' is the standard deviation.

One sided noise power spectral density N_0 is related to the standard deviation ' σ ' by

$$N_0=10\,log_{10}\left(\frac{1.6\sigma 2}{BW}\right) \quad (6)$$

BW – bandwidth of the signal

The signal reaches RAU (transceiver antenna) which is configured with 10dBi gain to support the received signal. The sensitivity of transceiver is fixed at -90dBm to support maximum of 1.0Gbps data rate. The required LNA gain of around 13dB is chosen for 2.4 GHz. The amplified signal from LNA is converted into digital signal with the help of analog to digital converter (ADC), parallel to serial converter & NRZ encoder.

The encoded data bits are externally modulated with MZM & CW Lorentzian Laser source. The operating wavelength and center emission frequency of laser source is chosen to be 1550 nm and 193.414 THz respectively. External modulation overcomes the chirping effect which is the major limiting issue in case of directly modulated Laser. The offset voltage and $V_л$ value is set to 5 volts and the chirp factor is made equal to zero in MZM unit. The power reduction due to modulation is observed to be 3dB.

In MZM the input Optical field is multiplied by a factor dependent on (i) input voltage V_{on} applied to the modulator arm (ii) the excess loss EL_{dB} introduced by the modulator (iii) the extinction ratio ER_{LIN} (iv) the chirp factor 'α' , then the output field can be defined as[23],

$$E_{out}=10^{-\left[\frac{EL_{dB}}{20}\right]}\left\{\cos\phi_D-j\left(\frac{1}{ER_{LIN}}*Sin\phi_D\right)\right\}e^{j\gamma E_{IN}} \quad (7)$$

$$\phi_D=\frac{\pi}{2}\left(\frac{\{V_{in}-V_{on}\}}{V_\pi}\right),\gamma=\left(\frac{1}{2}\right)\alpha\,ln\,P_{out},$$

$$\alpha=2P_{out}\left(\frac{\frac{d\vartheta}{dt}}{\frac{dP_{out}}{dt}}\right) \quad (8)$$

$$P_{out}=|\,E_{out}\,|^2$$

$$ER_{LIN}=\left[\frac{|E_{out}|_{max}}{|E_{out}|_{min}}\right] \quad (9)$$

The input electrical signal V_{in} is applied through a filter having the transfer function [23]

$$H(f)=\left[\frac{\sin\left(\frac{\pi f}{B_0}\right)}{\frac{\pi f}{B_0}}\right] \quad (10)$$

Where $B_0=2.25\ BW$

When the input voltage is equal to V_{on} the power of the optical signal is attenuated by excess loss only, so the modulator attains the state of maximum transmission. To switch over to the state of the minimum transmission a V_π Voltage must be applied in addition to the V_{on} voltage.

The externally modulated and amplified analog signal travels through a single mode fiber (SMF) of length 5 km. This link transports digitized signal between RAU and central base station (CBS) connected by SMF. The loss per km of the fiber is set to be 0.2 dB / km. The fiber link power is varied by varying the laser power also by placing suitable EDFA units along the link if necessary.

The fiber loss function $\alpha_{dB}(f)$ is defined [23] as follows

$$\alpha_{dB}(f)=\alpha_{0dB}(f)+\alpha_{1dB}(f)(f-f_{0loss})+\alpha_{2dB}(f))(f-f_{0loss})^2 \quad (11)$$

f_{0loss} = reference frequency

The dispersion value of the fiber at reference frequency /wavelength, D is chosen to be 16 ps /nm/km which is related to β_2 as,

$$D=-\left\{\frac{2\pi}{(\lambda r)^2}\right\}\beta_2 \quad (12)$$

λ_r = Reference wavelength

The attenuated and dispersed signal at the end of the fiber may go through suitable Optical amplifiers, filters and FBGs if necessary to overcome these effects.

At central base station (CBS), the received RF signal will be detected by a PIN detector with receiver sensitivity of -33.922dBm for an allowed error probability of 10^{-12} .

The sensitivity receiver is an easy tool to estimate the receiver sensitivity by carrying out sensitivity measurements [23]. By sensitivity, it is meant that the value of the average optical signal power at receiver input needed to achieve a certain BER performance, this includes an efficient semi-analytical technique that estimates the receiver BER vs. Received optical power. The test condition assumes direct detection in the absence of ASE (Optical). Sensitivity depends on the transmitted pulse shape, noise power and post detection filter.

Assuming a normal distribution for the noise, the BER [23] may be evaluated as

$$P(e) = \frac{1}{N}\sum_{i=1}^{N} P(e/V_i) \tag{13}$$

$$P(e) = \frac{1}{N}\sum_{i=1}^{N} \frac{1}{2} erfc \frac{(Vi - Vth)}{\sqrt{2\sigma^2}} \tag{14}$$

V_i = received signal samples at the sampling instant

V_{th} = Decision threshold

σ^2 = Variance of the noise at the sampling instant

The detected signal is filtered using raised cosine filter having -3 dB band width of 52 GHz. The signal is then regenerated with the help of threshold detector, serial to parallel converter and digital to analog converter (DAC) and demodulated with duo-binary MSK demodulator. The bits are detected, compared with transmitted bits and the error rate is calculated.

Assuming linear propagation and additive Gaussian ASE noise and neglecting polarization dependent loss (PDL), the BER of any coherent system can be expressed as a suitable function of the SNR evaluated over the constellation scattering diagram, at the decision stage of the Rx, after DSP.

$$BER = \psi(SNR) \tag{15}$$

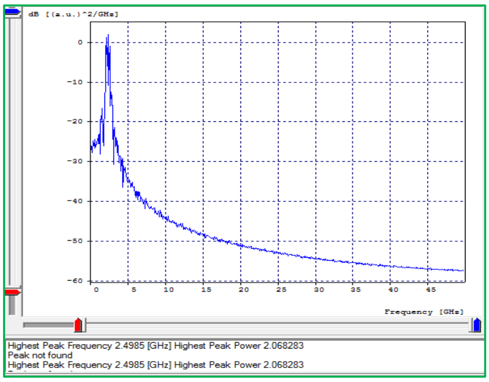
The function 'ψ' in Eq. (15) depends on the modulation format. As an example, for DMSK [23] we have:

$$BER = \frac{1}{2} erfc\left(\sqrt{SNR/2}\right) \tag{16}$$

5. Results and discussion

The minimum mobile EIRP required to achieve a bit error rate (BER) value of 10^{-12} for different link power values with 5 km fiber length for both 2.4 GHz and the 5 GHz RF band signals along with the required receiver sensitivity value are simulated and the results analyzed.

Fig. 9 (a) shows the duo binary MSK modulated RF spectrum at 2.4 GHz, Fig. 9 (b) shows the digitized signal after ADC and Fig. 9(c) shows the emission spectrum of CW Laser at 194.414 THz. Fig. 9 (d) depicts the detected electrical signal at the photo detector output. The corresponding spectrum, the receiver signal eye diagram and the BER vs. received power at the CBS is shown in fig 10 (a), (b) &(c) respectively.



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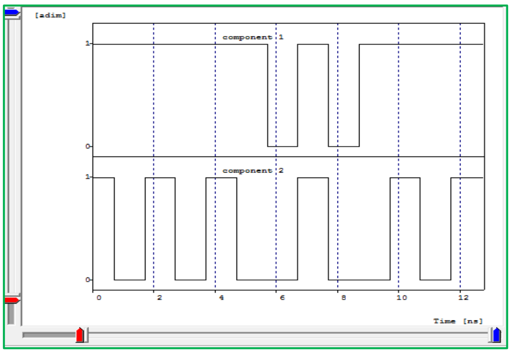
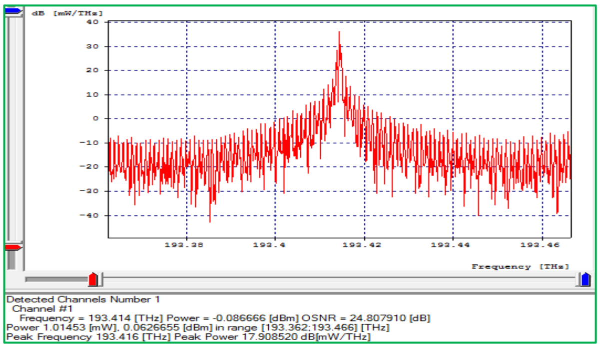
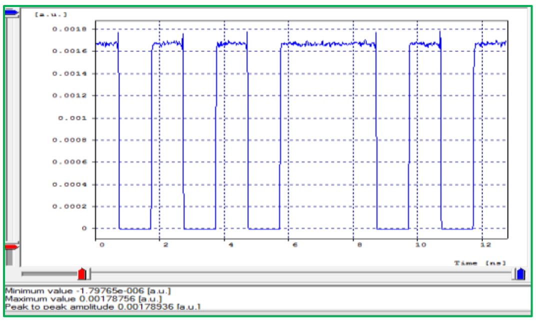


(b)

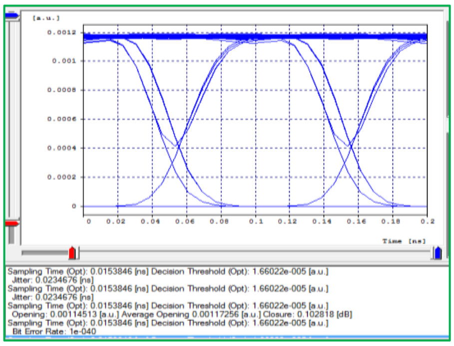


(c)

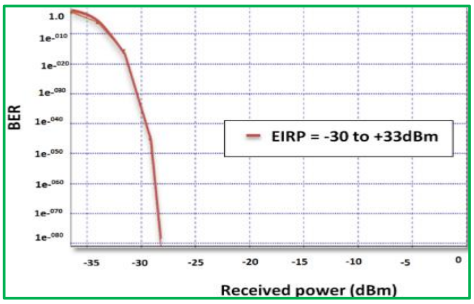


(d)

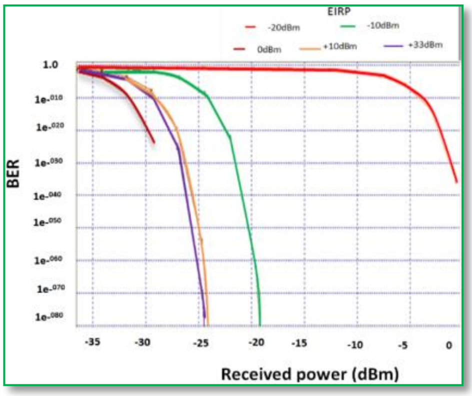
Fig. 9. (a) Duo-binary MSK modulated 2.4GHz spectrum (b) Digitized signal after ADC (c) Optical spectrum of LASER at 194.414THz (d) Electrical signal at Photo detector.



(a)



(b)



(c)

Fig. 10. (a) Eye diagram at Photo detector (b)BER Vs. Received power (CBS) -2.4 GHz (c) BER Vs. Received power (CBS) -5.0 GHz.

Table 5. Minimum Mobile EIRP required.

FIBER LINK POWER	MINIMUM EIRP (MOBILE UNIT) RF FREQUENCY 2.4GHz	MINIMUM EIRP (MOBILE UNIT) RF FREQUENCY 5.0GHz	FIBER LENGTH	BER
0dBm	-25dBm	-10dBm	5 Km	1.0e^{-40}

FIBER LINK POWER = LASER POWER + EDFA

EIRP = EFFECTIVE ISOTROPIC RADIATED POWER FROM MOBILE UNIT

Similar performance is also observed for RF signals at 5 GHz. It is inferred that the bits are recovered without significant errors at both the bands for the values specified for the wireless as well as the optical links. The 1.0e^{-40} value in the table 5 represents error free data in the photo detector and 1.0e^{-12} values represents the expected minimum BER value. The simulation results shown in this section suggest that a minimum transmitting power of only -25dBm for 2.4 GHz and -10dBm for 5.0 GHz band (Fig. 10b & c) is sufficient for good link performance. Hence a digitized RoF link based implementation of the access part of the mobile communication network considerably reduces the transmission power as well as the overall power requirements. The power hungry / less efficient power amplifiers may not be needed to establish quality link between MU and RAU (uplink) and vice versa for the above mentioned range of power levels (Table 5) and hence they can be eliminated in the MU and RAU (uplink-downlink case) thereby making the network energy efficient as well as free from electromagnetic pollution due to the small cell coverage approach [22].

6. Conclusion and future work

In this paper, the architectural changes that address energy efficiency, network capacity and the electromagnetic pollution aspects are proposed using digitized RoF system and small cell approach. The RoF link power budget highlights the significance of adopting the fiber backbone and taking it as close to the end user as possible in a cellular mobile communication system. The power consumption can be reduced by almost 99% , and the fact that power hungry power amplifiers (PA) having lower efficiency may be eliminated, is a significant motivation to adopt RoF based wireless access , at the same time increase the percentage of useful power, as seen from the tabled results. Further, since the radiated power is much smaller due to small cell configurations, the ensuing electromagnetic pollution will also be less, though the deployment cost may show some increase. Thus green advantage of the proposed architectural change like elimination of power amplifiers (PA) to improve the energy efficiency of the cellular network without compromising on the capacity is validated with help of digitized RoF. The capability of the proposed green architecture and the link to handle signals from multiple service providers and multimedia signals of differing QoS requirements need to be further analyzed.

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