5G Technology Enabling the Wireless Internet of Things

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Abstract New technology trend has been initiated worldwide for the exploration of IoT using 4G and 5G mobile communications, cloud RAN, and extended coverage beyond the coverage area of mobile network. Motivated by the above trends, ECE Department, SMIT has started to build one test bed for IoT using 5G. At first, some recent papers are reviewed toward practical perspective on IoT in 5G network issues related to (i) latency critical IoT applications in 5G, (ii) efficient IoT gateway over 5G wireless, and (iii) efficient 5G small cell planning with eMBMS for optimal demand response in smart grids. This paper will discuss the detailed development efforts to achieve the IoT test bed. Efforts are rendered to make the test bed as a high-end research facility, industrial consultancy, and support toward 5G-enabled wireless IoT.

Keywords RAN · NB-IoT · LTE · CR · DR · SG · ITS · PLR
SDR · SDN · RRH · DSO · FBMC · MXG · VSA · RSMA

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1 Introduction

As an addition to the traditional communication technology, more and more professionals engaged in the communication industry pay high attention to the Internet of Things (IoT). Recently, LTE and 5G technologies are enabling the Internet of Things [1]. 3GPP has published the standards for this in release-13 in June, 2016.

The major issues in realizing IoT service using LTE/5G are as follows:

Cat-NB1 (NB-IoT) flexible deployment options: Qualcomm proposes [2] narrowband Internet of Things (NB-IoT) flexible for deployment in four ways after the amendment of LTE 4G spectrum by 3GPP. Those four ways are (a) in-band LTE/5G IoT, (b) guard-band LTE/5G IoT, and (c) stand-alone LTE/5G IoT, and (d) shared access. The options (b) and (c) are static band allocation to place the NB-IoT spectrum as it deals with the frequency band outside the 4G LTE specified spectral range. But when option (a) is to be deployed, then some of the LTE subcarriers and resource blocks have to be deactivated, and in their positions, the NB-IoT spectral components comprising of one resource block (RB) are to be accommodated. But LTE can accommodate such eight NB-IoT RBs [3] to be placed in-band of LTE spectrum. In future, the proliferation of IoT devices may reach billions. Under that scenario, the no. of NB-IoT spectral components will be huge. So, in order to accommodate them, 4G LTE spectrum will not be able to give sufficient spectral accommodation to them. As a result, the 4G LTE has to be modified to new technology, 5G. As discussed above, the in-band LTE IoT can accommodate eight RBs of NB-IoT. To do this, firstly the eight RBs of NB-IoT spectrum have to be sensed and thereby eight RBs of 4G LTE band have to be removed. In those vacant positions (white spaces) of LTE band, the incoming eight RBs of NB-IoT would have to be placed. This method needs to be done by employing cognitive radio (CR) in cloud server level. Accordingly, the enabling NB-IoT spectrum has to be controlled at IoT end node level. So, the intermediate 5G wireless gateway must have to be flexible. The same will be utilized for option shared access for IoT (d).

Enabling mission-critical control IoT services: The mission-critical applications involve the following [4]: (i) industrial automation, (ii) process automation, (iii) smart grids (SG), and (iv) intelligent transport systems (ITS). The reliability and the latency of the systems are to be typically 10^{-9} packet loss rate (PLR), and latency should vary from 250 μs to 10 ms [5]. The improvement of physical layer and the network layer has to be done with proper protocol using software-defined radio (SDR) and software-defined network (SDN).

Extended coverage for IoT in 5G: For solving the communication problem in a hyper-remote area like Elephanta Island situated remotely in Indian Ocean and a far apart from Mumbai Harbor, it is recommended to establish a mesh hand over network among the boats running between harbor and the island. So, all the boats are needed to be IoT enabled, so that the mesh networking between the boats will be feasible.

2 A Case Study: Wireless IoT (W-IoT) Project Running at ECE Department, SMIT

Objectives: (i) Development of IoT end nodes for smart bulb to support the demand response mechanism; (ii) wireless IoT in 5G gateway development to establish a communication link at 60 GHz between the gateway and the IoT server. One resource block corresponding to NB-IoT demand is to be inserted by replacing one RB from the operational RBs within the 5G spectrum; (iii) the demand response engine is to be built in IoT server. The IoT server will receive the demand from remote IoT end nodes, and the decision toward proper response will be computed and communicated to IoT end nodes through the same communication link. Accordingly, the electrical bulb will be glowing or switched off. This technology is proposed in a smart grid (SG) system; (iv) the extension of the IoT end nodes is to be made feasible toward extended coverage through mesh network. This 4-folded objectives are depicted in Fig. 1. The highlighting features of the proposed test bed are that the above-mentioned three issues under article 1.1 have been taken care for the effective solutions.

3 Methodology and Prototyping

3.1 IoT_5G Gateway Prototyping

5G wireless network is a heterogeneous type of network where different remote radio heads (RRH) of different technology can be connected with a cloud-based

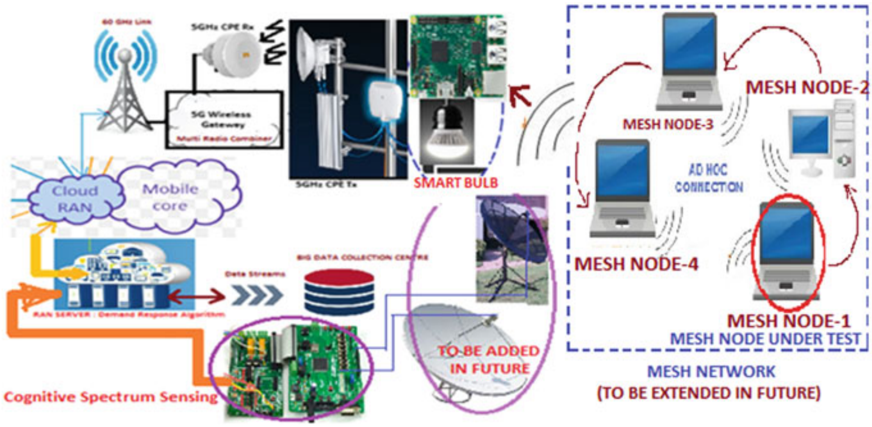

Fig. 1 A W-IoT test bed at ECE Department, SMIT, for demand response process of development of a smart bulb under smart grid application

computing server. The RRH will be connected with the cloud server using millimeter wave instead of optical front-haul cables. The low latency and higher data rate are achievable by using the 5G wireless gateway [6].

In the proposed system, the 5G wireless gateway is built out of the following ingredients:

(i) A 5-GHz customer premises equipment (IEEE 802.11an) as the receiver for receiving the control signal from IoT device.
(ii) The interface between the 5-GHz CPE receiver and the workstation is done by means of a digital storage oscilloscope (DSO) having a high sampling rate ($\sim$2 giga samples/s).
(iii) The workstation captures the control data of IoT from the specified channel of the DSO. The captured data is taken into SystemVue software platform.
(iv) The narrowband IoT (NB-IoT) modulation is done over the control signal. The NB-IoT signal is combined with the 5G BIGDATA. The modulation scheme used for generation of BIGDATA is filter bank multicarrier (FBMC). The multirate signal combiner is used for combining the two heterogeneous signals in SystemVue software.
(v) The combined signal is dumped to the arbitrary waveform memory of an Agilent Mixed Signal Generator (MXG). The I & Q output of the MXG is used for mmWave upconversion.
(vi) The I & Q output from the MXG is fed to the corresponding I & Q input of the 60-GHz transceiver board. It accepts the I & Q baseband and upconverts it to 60-GHz RF. This mmWave signal is transmitted through 60-GHz pyramidal horn antenna.
(vii) The 60-GHz RF is propagated through a 80 m length of channel after which the 60-GHz downconverter is present at the other end of the 5G IoT wireless gateway. The retrieved narrowband control signal is directly saved in the dynamic memory of the radio access network (RAN) server.
(viii) The decision-making algorithm exists within the RAN server. After the decision flag is generated, it is further constructed in the form of a particular signal. Here, this signal has been considered as a 1 kHz tone or 1 kHz square wave. This signal will basically signify the status of the end node device. So, this 1 kHz tone will be again retransmitted to the IoT end device through 5G wireless gateway.

3.2 IoT End Node Development

The IoT end device is considered here as an electrical lamp. The stand-alone lamp is a non-networked device. The objective is to make it a networked node for IoT compliant device. The enabling electronic part is achieved by means of a Raspberry Pi board. The smart algorithm is developed in Raspberry Pi in order to control the state of the lamp. The Raspberry Pi can control the electric lamp through a relay, and the Raspberry Pi kit can be interfaced with a 5-GHz CPE through its LAN port. The state (the lamp is 'ON') information is transmitted from Raspberry Pi board to the 5G wireless gateway through 5-GHz transmitter CPE.

4 IoT 5G Base Station

4.1 Remote Radio Head

The remote radio head (RRH) in the above system is comprised of the MXG, 60-GHz transceiver unit, waveguide, and V-band horn antenna. This RRH is acting as the radio gateway for passing the NB-IoT signal along with the voluminous 5G-modulated data.

4.2 Base Band Unit

The base band unit (BBU) is connected to the RRH. The BBU performs the demodulation of the NB-IoT signal and FBMC waveform. The baseband equalization is done in the BBU of the receiver. IoT server is connected to BBU through proper interfacing.

5 IoT Server for Demand Response

The IoT server is connected with the receiver BBU. The state of the electrical lamp (when it is 'ON') is received through the 60-GHz wireless link and properly demodulated by the BBU. Accordingly, the demands are processed and the decision is generated within the IoT server. Finally, the response is forwarded to the IoT end node through the return path.

6 End-to-End Simulation

Figure 2 represents the 5-GHz IEEE 802.11an link between IoT end node and 5G gateway.

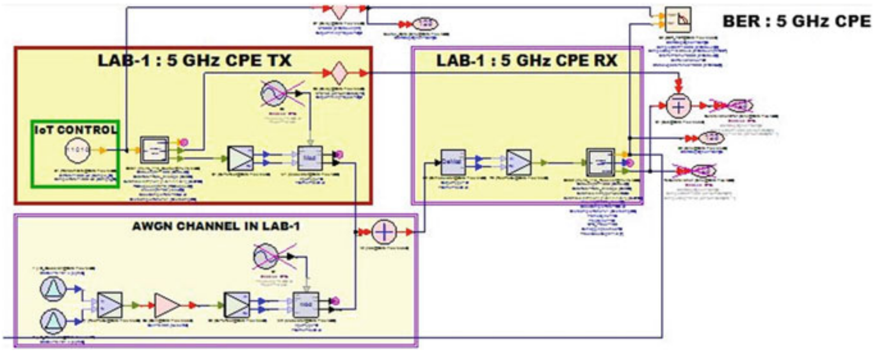

Fig. 2 5-GHz CPE link: IoT end node to 5G wireless gateway

7 Prototyping

7.1 Prototyping 1 (Guard-Band 5G IoT)

The simulated results are analyzed, and the prototyping of the above model has been initiated in the Department of Electronics and Communication Engineering, Sikkim Manipal Institute of Technology. To meet the goal of Center of Excellence, the total system is realized through a flexible 5G test bed situated at ECE research laboratory. The IoT end node to 5G gateway link is achieved by point-to-point 5-GHz Wi-fi (IEEE 802.11an) link.

The 5G modulation (FBMC waveform) part is realized in Agilent MXG. The wireless gateway link is achieved using 60-GHz transceiver unit.

Figure 3 depicts the simulation of the 5G gateway using multistandard radio (multiradio combiner). The above simulation model consists the block to retrieve the NB-IoT signal at the RAN server.

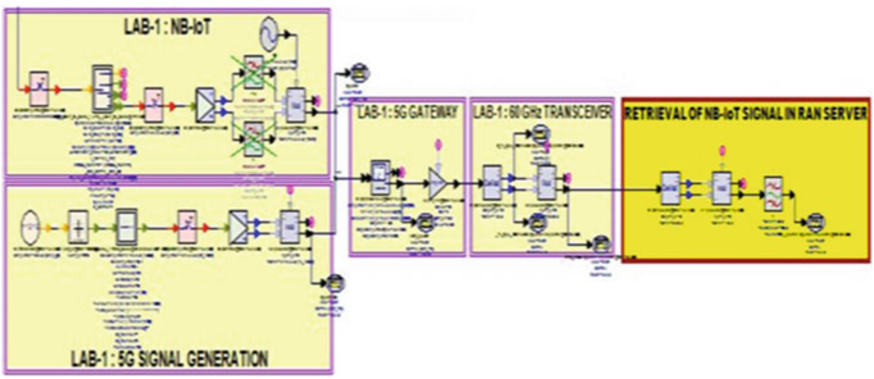

Fig. 3 Multiradio combiner and retrieval of NB-IoT signal in RAN server

Further, the design of the demand response algorithm is partially implemented in a server to control the IoT-enabled electrical lamp under consideration.

The whole system will be a miniaturized version of the above test bed as the system is to be finally delivered as an IoT product. The selection of V-band RF (60 GHz) exploits the advantage of mmWave to make the dimension of the system very small and portable.

8 Outcome and Expected Outcome

See Figs. 4 and 5.

9 Prototyping 2 (In-Band 5G IoT)

Frequency division multiplex (FDM) process is utilized for prototyping 2 with in-band 5G IoT. Both the spectrum positioning and spectrum power are flexible. The RBs for 5G and RBs for IoT can be multiplexed and placed anywhere with variable power level. The result is visualized using VSA along with Keysight 89,600 software. Further work toward this waveform design and resource spread multiple access (RSMA) is also initiated for efficient and effective coexistence of both 5G and IoT waveform.

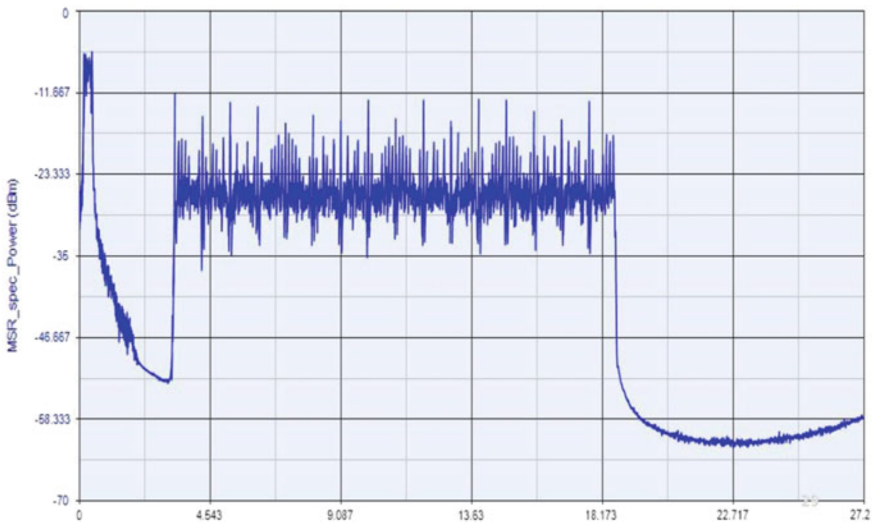

Fig. 4 NB-IoT control signal spectrum combined with wideband 5G spectrum

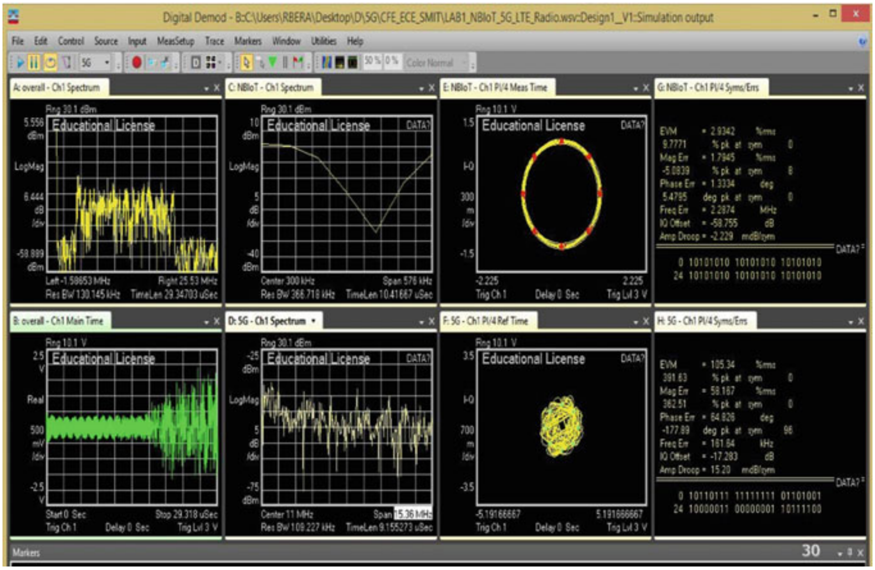

Fig. 5 NB-IoT symbol recovery through vector signal analyzer

10 Prototyping 3 (Extended Coverage)

Three laptops are configured in ad hoc mode of operation for communication and are the representative of extended coverage of the above IoT in 5G test bed. One KHz tone generated at the farthest laptop will reach to IoT end node via Laptop2 and Laptop3 using ad hoc communication. In turn, IoT end nodes will send this control signal of 1 kHz tone as demand response.

11 Summary and Conclusion

Motivated by the recent innovation of LTE and 5G technologies which are enabling the Internet of Things, one 5G-enabled IoT test bed is being established at the ECE Department, SMIT, to form the *Center of Excellence* in this technology area at the department.

The authors have highlighted some issues related to this technology realization while reviewing the recent articles. ***Spectrum coexistence issues*** like NB-IoT flexible deployment refer to in-band, guard-band, stand-alone, shared spectrum. The issue related to ***enabling mission-critical control IoT services*** dictates the redesign of the system toward a latency of the order of 1 ms or less and reliability figure 10e-9. The ad hoc mode of communication is being used worldwide to solve the issue related to extended coverage.

Based on the critical literature survey, reviews and findings, the issues and problem definitions, the authors have initiated the research work to realize ‘IoT in 5G’ test bed at ECE Department, SMIT. Objectives and the test bed configuration have been finalized. The methodology and prototyping are divided into following sublevels:

(i) IoT_5G gateway prototyping
(ii) IoT end node development
(iii) IoT 5G base station
(iv) IoT server for demand response
(v) IoT end node extension.

Simulation and hardware testing are also initiated toward the completion of the test bed. Thus, a world-class test bed toward IoT in 5G with cloud server and extended coverage is being realized at ECE Department, SMIT.

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