सत्यमेव जयते

TECHNICAL REPORT

M2M ENABLEMENT IN

POWER SECTOR

SPECTRUM REQUIREMENTS FOR PLC AND LOW POWER RF COMMUNICATIONS

TEC-TR-S&D-M2M-002-02

M2M POWER WORKING GROUP

ISO 9001:2008

TELECOMMUNICATION ENGINEERING CENTRE
DEPARTMENT OF TELECOMMUNICATIONS
MINISTRY OF COMMUNICATIONS & INFORMATION TECHNOLOGY
GOVERNMENT OF INDIA

RELEASE 2.0

NOVEMBER 2015

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Important Notice

Disclaimer

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Executive Summary

Release 1 of the Technical Report of the M2M Power Working Group (at TEC) on 'M2M Enablement in Power Sector' had introduced the relevance of M2M communication in the power sector. Apart from recommendations for fostering large scale deployment in this sector and challenges that prevent seamless connectivity, a comparison of the popular communication technologies applicable for various applications in the power sector was presented.

Electric utilities are going to use the power lines for smart grid applications. Both narrowband and broadband power line carrier (PLC) communication technologies are being demonstrated by a number of electric utilities in India. The fact that PLC communication uses the existing infrastructure for communications, that is, power lines, strengthens their case. After studying the current PLC demonstrations in India and taking into account the global scenario, it is recommended to allocate a frequency band of 0 - 500 KHz for narrowband PLC communications, 2 MHz - 200 MHz for broadband PLC communications and any other band (for narrowband or broadband PLC) on which new technologies may be developed. Utilities/owners of the power lines may choose appropriate technologies/protocols depending on their geographical and organisational requirements.

Furthermore, a study of additional spectrum requirement for low power RF devices for M2M/IoT/IoE/Smart Cities applications has been undertaken. It has been concluded that the existing de-licensed frequency band of 865-867 MHz would not be sufficient to cater to the billions of connected/smart devices that would be deployed in the near future. After undergoing a comprehensive quantitative analysis, it has been recommended to allocate a band of 10-12 MHz for low power RF devices.

1. Introduction

1.1 Background

The first Technical Report of the M2M Power Working Group was released along with four other reports on Remote Health Management, Intelligent Transport System, Safety & Surveillance and Gateway & Architecture and the National Telecom M2M Roadmap by the MoC&IT in May 2015. The Technical Reports are available at www.tec.gov.in/technical-reports/ and M2M Roadmap at http://www.dot.gov.in/ntcell .

1.1.1 The aim of the four sectoral reports was to examine the use cases in the concerned sector for M2M applications and carry out gap analysis and identify further action points.

1.1.2 Key recommendations in the Release 1.0 of the Technical Report on M2M Enablement in Power Sector included

a. Mandating IPv6 for all devices in near future
b. Allocating additional spectrum for low power RF devices in India
c. Allocating spectrum for Power Line Carrier (PLC) communications in India
d. Defining rules/regulations for Television White Space (TVWS) technology

1.1.3 Spectrum requirements for PLC communications and low power RF communications were identified as work items for the next release.

1.2 Major Milestone in the Power Sector

After the release of the first Technical Report (Release 1.0), a major activity took place. In August 2015, the Bureau of Indian Standards (BIS) published a new standard on smart meters, that is, IS 16444 (AC Static Direct Connected Watthour Smart Meter Class 1 and 2 – Specification) in which IPv6 has been made mandatory for smart meters. The IPv6 Roadmap Version 2 released by DoT also envisages replacement/upgradation of 100% of consumer premises equipment by December 2017.

1.3 Scope

This Technical Report (Release 2.0) features spectrum requirements for PLC and low power RF communications. Demonstrations on PLC usage in India is described in detail. A quantitative analysis is used to determine the amount of spectrum that is needed for the billions of M2M/IoT/IoE devices that will be deployed in smart cities for smart applications in the coming years.

2. Power Line Carrier Communications

2.1 Indian scenario

PLC technology is at a nascent stage in India. It can be used for providing last mile connectivity as well as for creating a wide area network. A key requirement of this technology is the existence of a clean network of cables for carrying information. Issues such as noise generated by different loads on the power line, dynamic changes in the line impedance and absence of trained man-power capable of bespoke engineering are some of the issues that will need to be addressed in order to make this technology ready to use. In addition to the above mentioned, there is no frequency band allocated for PLC communications in India.

2.2 Global Scenario

2.2.1 Narrowband PLC

Globally, IEEE 1901.2[1], PRIME, G3-PLC, ITU-T G.hnem[2], IEC 61334, TWACS, Meters&More, OSGP and HomePlug C&C are some of the popular standards/protocols available for implementing Narrowband PLC systems.

Table 1 throws more light into the technical details.

TABLE 1 - SNAPSHOT OF GLOBAL STANDARDS/PROTOCOLS ON NARROWBAND PLC SYSTEMS

Standard/Protocol	Frequency band	Maximum data rate
IEEE 1901.2 - 2013	<500 KHz	500 Kbps
PRIME	42-89 KHz	128.6 Kbps
G3-PLC	35-91 KHz	33.4 Kbps
ITU-T G.hnem	10-490 KHz	1 Mbps
IEC 61334	60-76 KHz	Upto 2.4 Kbps
TWACS	200-600 Hz	100 bps
Meters&More	3-148.5 KHz	28.8 Kbps (nominal) and 4.8 Kbps (effective)
HomePlug C&C	10-450 KHz	7.5 Kbps
OSGP	9-95 KHz	3.24 Kbps (raw channel rate) & 2.36Kbps (effective)

Source: ISGF White Paper on 'Need for Allocating a Frequency Band for Power Line Carrier Communications' published on December 18, 2014

[1] http://standards.ieee.org/findstds/standard/1901.2-2013.html

[2] Developed by ITU-T: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6094004&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6094004

2.2.2 Broadband PLC

Globally, IEEE 1901-2010, HomePlug Green PHY and ITU-T G.hn (G.9960/G.9961) are some of the popular standards/protocols for implementing Broadband PLC systems.

Table 2 throws more light into the technical details.

TABLE 2 - SNAPSHOT OF GLOBAL STANDARDS/PROTOCOLS ON BROADBAND PLC SYSTEMS

Standard/Protocol	Frequency band	Maximum data rate
IEEE 1901-2010	< 100 MHz	500 Mbps
HomePlug Green PHY	2-30 MHz	10 Mbps
ITU-T G.hn (G.9960/G.9961)	2-200 MHz	1Gbps

Source: ISGF White Paper on 'Need for Allocating a Frequency Band for Power Line Carrier Communications' published on December 18, 2014

2.2.3 Frequency band allocation for Narrowband PLC

Europe, USA, Japan and China are some examples of regions where frequency bands have been allocated for PLC communications. Table 3 mentions the regions and frequency bands allocated for PLC.

TABLE 3 - SNAPSHOT OF GLOBAL FREQUENCY ALLOCATION FOR NARROWBAND PLC COMMUNICATIONS

Region	Frequency band for Narrowband PLC
Europe	CENELEC A: 3-95 KHz for power utilities CENELEC B: 95-125 KHz for any application CENELEC C: 125-140 KHz for in-home networking with mandatory CSMA/CA protocol CENELEC D: 140-148.5 KHz Alarm and Security systems
USA	10-490 KHz
Japan	10-450 KHz
China	3-500 KHz

Source: ISGF White Paper on 'Need for Allocating a Frequency Band for Power Line Carrier Communications' published on December 18, 2014

2.3 Demonstrations of PLC technology in India

The prime users of PLC technology, the electric utilities, are keen to use the power lines for communications. The fact that PLC uses the existing infrastructure, that is, the power lines, strengthens their case. In the past few years, Indian electric utilities have undertaken several pilots to test PLC technology in the Indian context and the results have been extremely successful. Some of the key details regarding PLC demonstrations in India have been mentioned in the following Sections.

2.3.1 OSGP demonstration at TPDDL

2.3.1.1 Objective

The Open Smart Grid Protocol (OSGP) has been implemented at Tata Power Delhi Distribution Limited (TPDDL). The goal of the study was to test the reliability and speed of the Networked Energy Services (NES) System's load profile collection mechanism in a real-world installation under challenging conditions. The number of meters per transformer varied in this demonstration and three low-voltage grid sections were used. Each had a large number of meters per transformer and each had repeating functions in use (in order to put maximum load onto the network and provide the most difficult test possible). In addition, load profile information was collected once every day.

2.3.1.2 Scope of Installations

Scenario 1: 65 meters under one transformer. All consumers in the transformer covered. An underground network was used.
Scenario 2: 19 meters under one transformer. An overhead network was used.

2.3.1.3 List of parameters exchanged

In each scenario, the following testing methodology was used:

Each meter was configured to deliver a daily load varying between 10*4 channels to 12*4 channels based on 15-minute intervals. The test was performed for two consecutive weeks more than 6 months.

For each scenario, the meter configuration included

- Configuring the network to collect data at 15 minutes interval and transmitting every 6 hours to the Head End System (HES)
- Configuring alarm transmission immediately
- Automated billing data reads
- Automated load profile reads
- Automated device alarm collection
- Automated meter event log data collection
- On-demand power quality data reads
- On-demand instantaneous power reads
- On-demand billing reads
- On demand operation of the meter disconnect switch

- Maximum power limits: Turning off power to the consumer based on maximum instantaneous power consumption over a defined threshold
- Display of meter discovery data (automated topology management including phase description for each meter connected or meter down status)

Meters at different times were setup for transmission of data at 4 hours, 6 hours and in some cases every one hour to test the performance of the narrowband transmission and the GSM/GPRS connectivity.

2.3.1.4 Key findings

The NES System was proven to offer very high reliability and fast delivery of the load profile values to the data concentrator, as well as to the head-end enterprise system. In addition, no significant performance loss was observed when the number of channels was doubled.

Transmission of data from the smart meter to the Data Concentrator Unit (DCU) in all conditions was about 95 % on a four or six hourly basis. On a daily basis it increased to about 98 %. The pilot is still going on and the results will be validated once again. The non-delivering meters differed throughout the test period, so no data was lost.

However, in one transformer the mesh was not properly created as the number of end consumers with 600 units and above was very low. This transformer had over 400 consumers and it was sought to install meters in only 20 consumers. 14 meters communicated but rest did not communicate. The recommendation to add about 10 more meters was not implemented by the utility.

2.3.2 Meters and More demonstration at TPDDL

2.3.2.1 Objective

The objective of the pilot was to test the Meters and More protocol for smart metering application on one of the chosen overhead LT networks at TPDDL.

2.3.2.2 Scope of Installations

No of Meters Installed: 63
Single Phase Meters: 60
Three phase Meters: 3
Data Concentrator Unit: 1

93% of the total meters installed on the DT were installed with smart meters by Enel.

2.3.2.3 List of events/parameters sent from the smart meter to the utility

The frequency of acquisition was optimized (reading cycle of 6 hours) in order to guarantee full reachability of the meters installed, and to collect all the related readings within 24 hours. Data extracted from the AMI system shows that readings were successfully acquired from all the 63 meters installed with a performance that complies with Enel's standards (reachability index > 95% @24hr).

As already known, noise on network and GPRS communication issues varied dynamically throughout the whole day. By adopting a good reading cycle strategy, it is therefore possible to deal with temporary unreachability of some meters.

Data is related to:
- Active energy import current
- Active energy export current
- Maximum power demand import current with its date and time
- Maximum Power demand export current with its date and time

Load profiles
Based on the data acquired from field 100% of load profiles were successfully acquired, based on 12 times per day acquisition.

Power quality data
Based on the data acquired from field, 100% of voltage variations were successfully acquired, based on 4 times per day.

Interruptions Data
Interruptions recorded by the meter could be viewed at any moment from the HES.

2.3.2.4 Reliability in field

The reliability of PLC communications using Meters and More technology/protocol was around 94% for data transfer on a 6 hourly basis and it increased to about 98% on a 24 hour basis. The pilot is still going on and the results will be validated once again.

Other Indian utilities have also demonstrated the Meters and More protocol.

2.3.3 TWACS demonstration at UHBVN

As part of the 14 Government of India approved smart grid pilot projects, Uttar Haryana Bijli Vitran Nigam (UHBVN) is in the process of implementing smart grid functionalities at Panipat, a city that has a peak demand of 42 MVA, has 3 number of 33KV feeders and 8 number of 11 KV feeders. Also, it has 539 distribution transformers and the LT: HT ratio is 1.8:1. The AT&C losses are 23.15% and the number of consumers is 31623.

AMI and SCADA will be demonstrated in 3 feeders, namely Tehsil Camp, City -1 and Conduit Feeders.

Two Way Advanced Communications System (TWACS) protocol will be used for PLC communications which is a technology that uses 200-600 Hz of the spectrum. This technology will be used at Panipat for both, smart metering and SCADA.

The objectives of this project are:

- To reduce theft
- To improve the quality and reliability of power
- To shift the peal load to off-peak hours using demand response
- To study consumer consumption behaviour
- To perform outage management

The reliability of TWACS communications at Panipat is around 98%.

2.3.4 Multiple PLC protocols demonstrated at UGVCL

As part of the 14 Govt. approved smart grid pilot projects, Uttar Gujarat Vij Company Limited (UGVCL) has demonstrated Proof of Concepts (PoC) for 4 PLC protocols. The details are given in Table 4.

TABLE 4 - DETAILS OF PLC IMPLEMENTATION AT UGVCL

PoC	Protocol Used for Communication	Communication Frequency Range	1 phase			
			Meter to DCU		DCU to Central server	
			Technology	Nos. of Smart Meters installed	Technology	Nos. of DCU Installed
1.	DLT 645 2007	25 KHz to 478 KHz	PLC	295	GPRS	5
2.	Not defined in Documents	Not defined in Documents	PLC	235	GPRS	5
3.	PRIME	41.992 KHz to 88.867 KHz	PLC	297	GPRS	5
4.	Not defined in Documents	2 MHz to 12 MHz	PLC-Broadband over Power Line (BPL)	280	GPRS	5

2.3.5 PLC implementation at PGCIL

Power Grid Corporation of India Limited (PGCIL) is the oldest user of PLC technology in India. It uses PLC technology for both, protection and monitoring of the transmission grid. The frequency of operation is between 36 KHz and 500 KHz and the communication technology is proprietary. The system is working with a reliability of around 97-98%.The maximum throughput is 28 kbps. Around 99% of the 132 kV and above feeders are monitored and controlled by PLC communication.

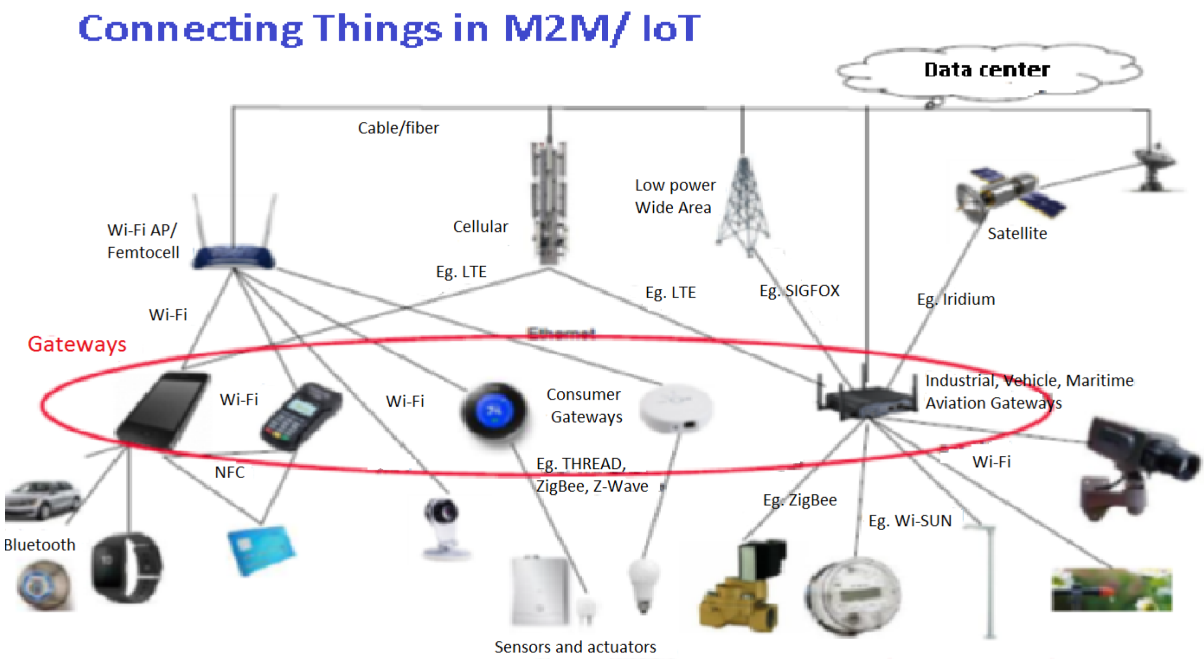
2.4 High level recommendations for PLC usage in India

There is an urgent need to allocate frequency bands for narrowband PLC communications. Subsequently, bands for broadband PLC may also be allocated. It is recommended to allocate a frequency band of 0 - 500 KHz for narrowband PLC, 2 MHz - 200 MHz for broadband PLC and any other band (for narrowband or broadband PLC) on which new technologies may be developed. Utilities/owner of the power lines may choose appropriate technologies/protocols depending on their geographical and organisational requirements.

3. Low Power RF Communications

Every one of us likes to have our smart phones, tablets, phablets etc. being seamlessly connected to the internet. With initiatives such as Machine to Machine (M2M) communications, Internet of Things (IoT), Internet of Everything (IoE), and Smart Cities, the number of 'connected' or 'smart' devices would exponentially increase. It is estimated that by 2020, there may be 26 billion to 50 billion connected devices as per different projections against a human population of 7.6 billion. About 10% of these devices may be deployed in India. This gap between the number of connected devices and humans would continue to increase; the former would surge past the latter. These would lead to enormous business opportunities as well. Apart from established firms showing interest in these areas, the number of start-ups in these domains is rising steeply. Various communication technologies, gateways and devices have been shown in Figure 1.

FIGURE 1 – TYPICAL M2M/IOT NETWORK



Source: Adopted from Keysight Technologies

In a discussion chaired by Sr. DDG, TEC at India Smart Grid Week (ISGW) in March 2015 at Bangalore, global Industry experts had the view that India would certainly need more spectrum for low power RF devices in near future. It was also agreed that the Industry, in coordination with India Smart Grid Forum (ISGF), would study and project the requirement of spectrum. Accordingly, a study was undertaken which is explained in the following Sections.

A comparison of popular wireless communication technologies is depicted in the Table 5.

TABLE 5 – COMPARISON OF POPULAR WIRELESS COMMUNICATION TECHNOLOGIES

Standard	Freq.	Max. BW	Data Rate	Modulation	Range	Network	Applications
LTE-M Category 0/1 (LTE Rel12/13)	LTE Band	1.4 MHz	200 kbps - 1 Mbps	OFDM	1000 m	WMAN	Lower speed and power versions of the LTE standard defined in Rel12/13
IEEE 802.11ah	Sub GHz	1 - 16 MHz	150 kbps - 78Mbps	OFDM	1000 m	WLAN	Target for IoT, wearable devices or extend range
IEEE 802.11p	5.8 - 5.9 GHz	5/10/20 MHz	1.5 Mbps - 54 Mbps	OFDM	1000 m	WLAN	Wireless Access in Vehicle Environment (WAVE)
Bluetooth Low Energy	2.4 GHz	1 MHz	1 Mbps	GFSK	50 m	WPAN	Automotive, healthcare, security, home entertainment
Z Wave (ITU G.9959)	868.42 MHz 908.42 MHz	200 KHz	9.6 kbps - 100 kbps	BFSK GFSK	100 m	WPAN	Remote controls, smoke alarms, security sensors owned by Denmark Zensys
ZigBee (IEEE 802.15.4)	ISM<2.4 GHz	2 MHz	40 - 250 kbps	BPSK OQPSK	10 m	WPAN	Home automation, smart grid, remote control
Thread (IEEE 802.15.4)	ISM<2.4 GHz	2 MHz	40 - 250 kbps	BPSK, FSK, OQPSK	10 m	WPAN	Mesh network for home and support 6LoWPAN
Wi-SUN (IEEE 802.15.4g)	ISM<2.4 GHz	200 KHz - 1.2 MHz	50 kbps - 1 Mbps	FSK, OFDM, OQPSK	1000 m	WNAN	FAN and HAN smart utility networks, smart grid
NFC (ISO/IEC 18092)	13.56 MHz	1 MHz	848 kbps	PSK, ASK	20 cm	P2P	Contactless payment, easy other connection (Wi-Fi, BT), identity and access

Source: Keysight Technologies

Please note that typical values are used in the above table. These characteristics may vary in actual implementations.

3.1 Machine to Machine, Internet of Things, Internet of Everything, and Smart Cities

3.1.1 Indian Scenario

With the Government of India announcing that 100 smart cities will be developed in the near future, Internet of Things (IoT), Internet of Everything (IoE) and Machine to Machine (M2M) communications have become popular names in the technology circles.

The Ministry of Urban Development (MoUD)[3] has announced a Smart Cities Mission to drive economic growth and improve the quality of life of people by enabling local development and harnessing technology as a means to create smart outcomes for citizens. Prior to this initiative, a concept note

[3] http://indiansmartcities.in/downloads/CONCEPT%20NOTE-13-10-2014_mkgnew.pdf

on smart cities was published wherein Social Infrastructure, Physical Infrastructure, Institutional Infrastructure and Economic Infrastructure were identified as the four pillars of a smart city.

A National Smart Grid Mission (NSGM) is expected to be launched very soon[4]. As part of this mission, smart grids are envisioned to be built in 30 smart cities.

The Department of Telecommunications (DoT) has formulated a roadmap for deployment of M2M communications in India which was released on May 12, 2015.

The Telecommunication Engineering Centre (TEC) formed M2M Working Groups on M2M Power, M2M Health, M2M Automotive, M2M Surveillance, and M2M Gateway and Architecture to delve deeply into the these domains of M2M Communications. Technical Reports on M2M enablement in sectors such as Health, Transport, Power and Safety & Surveillance, and M2M Gateway and Architecture were released by TEC on May 12, 2015. Recently, TEC has formed new working groups on Smart Homes, Smart Cities, Smart Villages & Agriculture, Smart Governance and Environment Monitoring & Pollution Control.

India Smart Grid Forum (ISGF)[5] has prepared a standard framework for smart cities which includes an Interdependency Matrix and Maturity Model for smart cities.

3.1.2 Global Scenario

Earlier this year, ISO has released a standard (ISO 37120[6]) on sustainable development of communities that defines and establishes methodologies for a set of indicators to steer and measure the performance of city services and quality of life.

The Smart Cities Council (SCC) has recently released a 'Readiness Guide'[7] that aims to guide the transition to a smart city. Moreover, it is a useful mechanism to understand the totality of a smart city and how the pieces work together.

ITU has formed a focus group[8], 'ITU-T Focus Group on Smart Sustainable Cities (FG-SSC)' which would focus on the telecommunications aspect, electromagnetic field considerations and key performance indicators in smart sustainable cities.

In addition, ITU has recently constituted a study group, 'ITU-T Study Group 20: IoT and its applications, including smart cities and communities' which will be responsible for international standards to enable the coordinated development of IoT technologies, including M2M communications and ubiquitous sensor networks.

[4] Office Memorandum of NSGM was issued by Ministry of Power (MoP) on March 27, 2015: http://powermin.nic.in/upload/pdf/National_Smart_Grid_Mission_OM.pdf

[5] http://www.indiasmartgrid.org/smartcityproject.php

[6] http://www.iso.org/iso/catalogue_detail?csnumber=62436

[7] http://www.futuregov.asia/articles/4345-smart-cities-council-readiness-guide

[8] http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

3.2 Use case for low power RF technology

3.2.1 Why low power RF technology?

Low power RF is considered to be the most effective communications technology that would offer connectivity to a plethora of applications. The main reasons for these include (but are not limited to) low operating cost, less power dissipation, long range (if sub-GHz frequency bands are used), good coverage and penetration.

3.2.2 Application areas

Low power RF communications would be the most popular communications technology in smart cities. The list of applications that would use this technology is mentioned in Table 6.

TABLE 6 - LIST OF APPLICATIONS FOR LOW POWER RF DEVICES

Electricity (Grid) • Advanced Metering Infrastructure • Distribution and Substation Automation • SCADA/DMS and SCADA/EMS • DCS for GENCOs • WAMS • Distributed Generation • Energy Storage • Microgrids • Home Energy Management/Building Energy Management	Buildings (Automation and Management) • Residential Buildings • Commercial Buildings • Industrial Buildings • Shopping Malls
Renewable Energy	EV Charging Stations
Gas	Parking Lots
Water Distribution: • Portable Water • Non-portable Water • Industrial Water • Agricultural Water • Other Water Bodies (Ponds, Lakes, Tanks etc.)	Hospitals and E-Healthcare • Primary Healthcare Centres • Super Specialty Hospitals • E-Healthcare
Rivers and Canals – Monitoring and Management	Theaters and Auditoriums
Waste Collection, Monitoring and Management • Hazardous Waste (Toxic/Reactive/Corrosive/Explosive) • E-Waste • Medical/Bio-Medical Waste • Sanitation and Sewage	Places of worship

• Rain Water/Storm Water/Drainage • Radio Active Waste • Municipal Solid Waste (incl. Religious Waste)	
Sports Academies	Training Centres

Source: ISGF White Paper on Smart Cities

3.3 Quantitative analysis of spectrum requirement

In this Section, a detailed analysis for different technical parameters is undertaken for arriving at spectrum requirement for India.

3.3.1 Typical Unit Cell Size

In order to calculate the number of radio devices in a unit cell, a unit cell area needs to be defined.

To define a unit cell, the following assumptions have been considered:

1. Typical device range : 800 meters
2. Typical device range in multi hop mode : 300 meters
3. Typical number of hops : 5

Based on the above conditions, the following can be deduced:

- A typical single hop node with range of 800 meters will be able to communicate with any device in cell with a radius of 800 meters.
- In case of multi hop network, a device will be sending a packet to an end node placed (300x5 = 1500 meters) in any direction. This makes the cell radius of 1.5Km.

From these two inferences, the unit cell area could have a radius of 2 Sq Km or as high as 7 Sq Km.

For the calculation below, a best case of 2 Sq Km has been considered.

3.3.2 Expected Number of M2M/IoT/IoE Devices operating in one unit cell (2 Sq Km)

Based on Indian Census 2011, the most densely populated area had 7897 persons living in one Sq Km[9]. (Kolkota Metropolitan Area had a total population of 14,035,959[10] living in 1,886.67.41 Sq Km[11]). For this calculation, a moderate value of 5000 persons per Sq Km has been considered.

Based on studies done across the globe by various groups/teams, the number of M2M/IoT/IoE devices is growing exponentially every year. A study done by Cisco Internet Business Solutions Group (IBSG), has estimated that the number of connected devices would rise to 6.58 devices[12] per human being by 2020. This number was 0.08 in 2003 which increased to 1.84 in 2010 and to 3.47 in 2015.

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[9] https://en.wikipedia.org/wiki/List_of_metropolitan_areas_in_India
[10] http://www.census2011.co.in/census/city/215-kolkata.html
[11] http://www.kmdaonline.org/pdf/aar11/introducing_kma.pdf
[12] http://www.iotsworldcongress.com/documents/4643185/0/IoT_IBSG_0411FINAL+Cisco.pdf

Based on the above facts, the expected number of M2M/IoT/IoE devices in a 2 Sq Km unit cell will be

= Population Density x 1 Unit Cell area x connected devices per person
= 5000 x 2 x 6.58
= 65800 Nodes in one unit cell

3.3.3 Expected data traffic in one unit cell

To calculate the data traffic, a RF mesh network using IEEE 802.15.4 Physical/MAC layer, 6LoWPAN, IPv6, ROLL/RPL, UDP has been considered.

Typically a node transmits 150 bytes of data over the air which includes the sensor data as well as the overhead of all layers every minute (60 seconds).

Considering the mesh network (and occasional retransmission of the packet) each packet is transmitted over air on average 5 times before it reaches the destination.

From this assumption, the expected amount of data transmitted over the air by all devices in a unit cell will be

= Number of devices in unit cell x Number of bytes transmitted by each node x Number of times each packet is transmitted over air
= 65800 x 150 x 5 bytes per minute
= 49350000 bytes per minute
= 394800000 bits per minute
= 6580000 bits per second

3.3.4 Expected Bandwidth required

The average time taken to transmit one bit (including CSMA-CA, etc.) on an average hardware platform is:

- 15-20 uSec (including overhead) at 50Kbps Data Rate
- 8-11 uSec (including overhead) at 100Kbps Data Rate

Case 1: 50Kbps (15uSec per bit)

Time required to transmit the 6580000 bits: 98700000 uSec (~100 Seconds)

The amount of data that is required to be transmitted each second is taking 100 Seconds (approx.) which can only be achieved if there exist 100 channels and different devices using different channels to operate. So transfer this amount of data we will need 100 different channels.

With 200 KHz channel separation, the frequency band required to handle this data will be:

= Channel separation x Number of channels
= 200 KHz x 100
= 20000 KHz
= 20 MHz

Case 2: 100Kbps (8uSec per bit including overhead)

Time required to transmit the 6580000 bits: 52640000 uSec (~52 Seconds)

The amount of data that is required to be transmitted each second is taking 52 Seconds (approx.) which can only be achieved if there exist 52 channels and different devices using different channels to operate. So transfer this amount of data we will need 52 different channels.

With 400 KHz channel separation the Frequency band width required to handle the data we will need:

= channel separation x Number of channels
= 400 KHz x 52
= 20800 KHz
= 20.8 MHz

3.3.5 What we can achieve in existing 2 MHz band (865-867 MHz band)

Based on the same assumptions and calculations mentioned in the above Sections, the existing 865-867 MHz band is examined below.

For Data Rate 50Kbps:

Data that can be transmitted in one channel in 1 Sec (15uSec per bit):		66,667 bits [= 1/(15 x 10^{-6})]
		= 8,333 bytes per second
Number of bytes transmitted in 60 seconds in one channel	:	5, 00,000 bytes
Number of packets (150 bytes each) in one channel	:	3,333 packets in 60 seconds
Each packet takes 5 hops, actual number of packet in one channel	:	667

With a channel separation of 200 KHz, 10 channels are available, so the total number of devices that can operate in one unit cell is 6670.

Based on the above calculation, using the current frequency band of 2 MHz can permit 6670 nodes in a unit cell. This might be sufficient for one type of application (for example smart metering) but when a smart city is considered, the 2MHz band will definitely not be sufficient.

3.3.6 Inferences

Though the analysis done above considers that all M2M/IoT/IoE devices will use the same frequency band, in practice, different vendors/users might use different technologies occupying different frequency bands.

But since the sub-GHz band is most effective for smart city applications, majority of the devices will be operating in this band. Hence it is safe to assume that at least 50 to 60 % of the M2M/IoT/IoE devices will be using the sub- GHz frequency band.

Keeping in view the analysis done above, it is recommended that a frequency band of 10-12MHz for low power RF devices may be allocated.

3.4 Choice of frequency band

Selecting the frequency band is of utmost importance. The sub-GHz frequency bands offer compelling advantages as compared to other (higher) frequency bands. Below 1GHz, the further down we go, the better the performance will be in terms of range, interference and penetration. This assumes that the devices will only be sending incremental amount of data at regular intervals. The advantages of using a lower frequency band include (but are not limited to):

- Long range
  Range is inversely proportional to frequency and hence the range at the same output power and receiver sensitivity offered by sub-GHz bands is much more than that provided by the higher frequency bands.
- High signal-to-noise ratio because of low interference
  The 2.4-2.4835 GHz band is used by Wi-Fi and Bluetooth devices, microwave ovens, cordless phones etc. This has increased the traffic in this band and hence interference is a serious issue. The sub-GHz bands are much less congested and hence offer enhanced quality of service.
- Low power consumption
  Since the power dissipation is directly proportional to frequency of operation, a device operating in sub-GHz bands will consume less power.
- Deep penetration
  Since low frequency signals are reflected to a lesser extent, signals in the sub-GHz penetrate deeper into thick walls.
- Low Total Cost of Ownership (TCO)
  Since sub-GHz bands offer a higher range at same output power and receiver sensitivity, less number of repeaters/concentrators are needed. Hence the TCO is lower when sub-GHz bands are used for communications.

3.5 Current scenario of the de-licensed bands

The previous report (Release 1.0 of 'M2M Enablement in Power Sector') mentioned the specifications of the de-licensed bands in India. A snapshot of this is depicted in Table 7.

TABLE 7 - SNAPSHOT OF SPECIFICATIONS OF THE DE-LICENSED BANDS IN INDIA

Frequency Band	Power Requirements	Antenna	Use of this frequency band
433-434 MHz	Maximum Effective Radiated Power: 10mW Maximum Channel Bandwidth: 10KHz	In-built.	Indoor applications.
865-867 MHz	Maximum Transmitted power: 1W Maximum Effective Radiated Power: 4W Maximum Channel Bandwidth: 200KHz	Nothing specified.	Any low power device or equipment.
2.4-2.4835 MHz	Maximum Transmitted Power: 1W (in a spread of 10 MHz or higher)	Nothing specified.	Any low power device or equipment.

	Maximum effective radiated power: 4W Maximum antenna height: 5 metres above the roof-top of an existing authorised building		
5.150-5.350 GHz and 5.725-5.875 GHz	Maximum Mean Effective Isotropic Radiated Power: 200mW Maximum Mean Effective Isotropic Radiated Power Density: 10mW/MHz in any 1MHz band	In-built or indoor.	Indoor applications which include single contiguous campus of an individual, duly recognised organisation or institution.
5.825-5.875 GHz	Maximum Transmitted Power: 1W in a spread of 10 MHz Maximum Effective Isotropic Radiated Power: 4W	Nothing specified.	Any low power device or equipment installed at outdoor locations.

3.6 Global Frequency Spectrum Allocation Scenario

Globally, various countries have allocated un-licensed frequency bands in excess of 7 MHz. North America and South America have allocated the most (26 MHz) in the sub-GHz band. Australia also believes that de-licensing a substantial amount of spectrum is the way forward and has allocated 13 MHz. Europe, Africa and most middle-eastern countries have access to 7 MHz of un-licensed spectrum. Moreover, Japan has de-licensed 8 MHz for M2M/IoT/IoE/Smart Cities initiatives.

Table 8 shows wireless frequency spectrum allocation in some countries/regions.

TABLE 8 - SNAPSHOT OF GLOBAL FREQUENCY ALLOCATION FOR WIRELESS COMMUNICATIONS

Country	Frequency Band
North America and South America	433.075-434.775 MHz and 902-928 MHz
Africa and Middle-Eastern countries	433.05-434.79 MHz and 863-870 MHz
Europe	433.05-434.79 MHz, 863-870 MHz, 870 – 876 MHz
Japan	426-430 MHz and 920-928 MHz
Australia	915-928 MHz
India	865-867 MHz and 433-434 MHz

3.7 Need for immediate action

There is an urgent need to allocate additional frequency bands in the sub-GHz range. These will lead to substantial gains in reliability due to massive reduction in network congestion.

As on today, only 2 MHz is available as un-licenced spectrum which can be used for low power wireless applications. Even if the additional 1 MHz in the 433-434 MHz band available for indoor applications is considered, it is apprehended that India would not be able to cater to the billions of devices that would be deployed in the M2M/IoT/IoE/Smart Cities initiatives.

If a reactive approach is adopted and additional spectrum is allocated after the network gets congested, a number of large scale projects may not be successful as interoperability issues will start showing up. This is because the installed devices may not have the capability to operate in the additional spectrum that would be allocated.

Hence, rather than taking a reactive approach by allocating additional spectrum 'as and when required', a proactive approach is needed by acting in advance and allocating an optimum amount of de-licensed spectrum.

3.8 A snapshot of the top contender bands

The 400 MHz bands and 800 MHz bands are top contenders for allocating additional frequency bands. Table 9 throws light more into the current scenario of spectrum allocation as per the National Frequency Allocation Plan (NFAP) 2011.

(The de-licensed bands are highlighted.)

TABLE 9 - SNAPSHOT OF TOP CONTENDER BANDS FOR ADDITIONAL SPECTRUM ALLOCATION IN INDIA

Frequency Bands/Spots	Usage as per NFAP 2011
380-389.9 MHz, 390-399.9 MHz, 410-430 MHz	May be considered for digital radio trunked systems on a case-by-case basis.
402-405 MHz	Very low power remote cardiac monitoring RF wireless medical devices, medical implant communication/telemetry systems and other such medical RF wireless devices.
406.1-450 MHz	May be considered for digital seismic telemetry on a case-by-case basis.
410-420 MHz	Fixed mobile (except aeronautical mobile) and space research.
420-430 MHz	Fixed mobile (except aeronautical mobile) and radiolocation.
430-432 MHz	Radiolocation, fixed mobile (except aeronautical mobile) and amateur services.
432-438 MHz	Radiolocation, fixed mobile (except aeronautical mobile), amateur and Earth exploration-satellite (active).
433-434 MHz	Low power short range devices for indoor applications on a non-interference, non-protection and non-exclusive basis.

434-438 MHz	Amateur service.
436.525 MHz	Earmarked for demonstration of equipment on non-interference, non-protection and non-exclusive basis.
438-440 MHz	Radiolocation, fixed mobile (except aeronautical mobile) and amateur services.
440-450 MHz	Fixed mobile (except aeronautical mobile) and radiolocation.
441.6 MHz	May be considered for anti-collision device applications on a case-by-case basis.
450-460 MHz	Fixed mobile.
450.5-457.5 MHz and 460.5-467.5 MHz	May be considered for IMT applications on a case-by-case basis.
460-470 MHz	Fixed mobile, meteorological satellite (Space to Earth)
466.8 MHz	May be considered for anti-collision device applications on a case-by-case basis.
470-520 MHz and 520-585 MHz	Will be considered for fixed and mobile services on a case-by-case basis.
806-890 MHz	Broadcasting and mobile satellite services except aeronautical mobile satellite service may be con
806-811 MHz	Earmarked for mobile trunked radio system to be used predominantly for captive networks. May be considered for requirements for Public Mobile Radio Trunked Systems which cannot be met in any other bands.
811-814 MHz	Earmarked for spectrum efficient digital Public Mobile Radio Trunked Systems (PMRTS) and Captive Mobile Radio Trunked Systems (CMRTS).
814-819 MHz	Earmarked for mobile radio trunked systems to be used predominantly for PMRTS.
819-824 MHz	May be considered for PMRTS and CMRTS.
824-844 MHz	Earmarked for cellular telecommunication systems, including WLL.
849.0125-849.1250 MHz	SCADA applications except for a few locations
851-856 MHz	Earmarked for mobile trunked radio system to be used predominantly for captive networks. May be considered for requirements for PMRTS which cannot be met in any other bands.
856-859 MHz	Earmarked for spectrum efficient digital PMRTS and captive mobile radio trunked systems.
859-864 MHz	Earmarked for mobile radio trunked systems to be used predominantly for PMRTS.
864-869 MHz	May be considered for PMRTS and CMRTS.
865-867 MHz	Low power devices or equipment for any application.
869-889 MHz	Earmarked for cellular telecommunication systems, including WLL.
890-902.5 MHz and 935-947.5 MHz	Earmarked for cellular telecom systems.
902.5-915 MHz and 947.5-960 MHz	May be considered for cellular telecom systems on a case-by-case basis.

3.9 High level recommendations for low power RF communications in India

From the quantitative analysis shown in Section 3.3, it is noted that the existing 2 MHz (865-867 MHz) would not be sufficient to cater to the billions of M2M/IoT/IoE devices that would be deployed in the near future. Based on the calculations in the above Sections, it is recommended to allocate a frequency band of 10-12 MHz for catering to these devices. In addition, the permissible channel spacing may be increased to 400 KHz (maximum) for reducing adjacent channel interference and to achieve higher data rates.

4. Detailed recommendations on PLC and low power RF communications

4.1 Power Line Carrier (PLC) communications

Following are some recommendations which may be worked upon:

I. It is recommended to allocate a frequency band of 0 - 500 KHz for narrowband PLC, 2 MHz - 200 MHz for broadband PLC and any other bands (for narrowband or broadband PLC) on which new technologies may be developed.

II. Utilities may be allowed to provide telecommunication services by using (Broadband over Power Line) BPL technologies. DoT may formulate an appropriate policy on this, including the licencing requirements if a utility wants to provide commercial broadband services.

III. Utilities may choose appropriate technologies/protocols depending on their geographical and organisational requirements.

4.2 Low Power RF communications

- **Frequency bandwidth**

Though the analysis done in above Sections considers that all M2M/IoT/IoE devices will use the same frequency band, in practice, different vendors/users might use different technologies occupying different frequency bands.

But since the sub-GHz band is most effective for smart city applications, majority of the devices will be operating in this band. Hence it is safe to assume that at least 50 to 60 % of the M2M/IoT/IoE devices will be using the sub- GHz frequency band.

Keeping in view the analysis done in Section 3.3, it is recommended that a frequency band of 10-12MHz for low power RF devices may be allocated.

Additionally, it is recommend to allocate the frequency band in the lower frequency range (<1 GHz) as it will help signals to penetrate obstacles more effectively while providing better range, signal to noise ratio and power consumption (of devices/sensors).

- **Frequency band selection**

As per the National Frequency Allocation Plan (NFAP) 2011, over 35 MHz have been provisioned for Public Mobile Radio Trunked Systems (PMRTS) and Captive Mobile Radio Trunked Systems (CMRTS) as shown in Table 9. There may be a possibility of freeing spectrum after the examination of the current usage of PRMTS and CMRTS. Freed spectrum can be earmarked to meet the demand of M2M/IoT/IoE communications. It will be preferable to have the spectrum close to the current de-licensed band of 865-867 MHz.

- **Channel Separation**

It is recommended to provide adequate inter-channel spacing in order to minimize the neighbouring/adjacent channel interference and to achieve higher data rates. Hence a channel spacing of 400 KHz (maximum) may be allowed instead of the present spacing of 200 KHz (maximum).

5. References

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- India Smart Grid Forum (ISGF) White Paper on '**Additional Spectrum for Low Power RF Communications for M2M, IoT, IoE Devices in Smart Cities**' published on November 02, 2015
- '**Smart Grid Vision and Roadmap for India**' released by Ministry of Power, Government of India in September 2013
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- CISCO White Paper on 'The Internet of Things' - http://www.iotsworldcongress.com/documents/4643185/0/IoT_IBSG_0411FINAL+Cisco.pdf

Abbreviations

Table 10 - Abbreviations

Abbreviation	Full Name
MoC&IT	Ministry of Communications & Information Technology
DoT	Department of Telecommunications
TEC	Telecommunication Engineering Center
IoT	Internet of Things
IoE	Internet of Everything
M2M	Machine to Machine
WPC	Wireless Planning and Coordination
MoP	Ministry of Power
NSGM	National Smart Grid Mission
MoUD	Ministry of Urban Development
ISGF	India Smart Grid Forum
ISO	International Organisation for Standardisation
SCC	Smart Cities Council
ITU	International Telecommunication Union
SCADA	Supervisory Control And Data Acquisition
DMS	Distribution Management System
EMS	Energy Management System
DCS	Distributed Control System
GENCOs	Generation Companies
WAMS	Wide Area Monitoring System
EV	Electric Vehicle
TCO	Total Cost of Ownership
NFAP	National Frequency Allocation Plan
PMRTS	Public Mobile Radio Trunked System

Abbreviation	Full Name
CMRTS	Captive Mobile Radio Trunked System
WLL	Wireless Local Loop
IBSG	Internet Business Solutions Group
MAC	Media Access Control
IPv6	Internet Protocol version 6
6LoWPAN	IPv6 over Low Power Wireless Personal Area Network
ROLL	Routing Over Low power and Lossy networks
RPL	Routing Protocol for Low-Power and Lossy Networks
UDP	User Datagram Protocol
CSMA	Carrier Sense Multiple Access
CA	Collision Avoidance
RF	Radio Frequency
PLC	Power Line Carrier
AMI	Advanced Metering Infrastructure
DCU	Data Concentrator Unit
AP	Access Point
TVWS	Television White Space
BIS	Bureau of Indian Standards
IS	Indian Standard
TWACS	Two Way Advanced Communications System
OSGP	Open Smart Grid Protocol
TPDDL	Tata Power Delhi Distribution Limited
UGVCL	Uttar Gujarat Vij Company Limited
UHBVN	Uttar Haryana Bijli Vitran Nigam
PGCIL	Power Grid Corporation of India Limited
CENELEC	European Committee for Electrotechnical Standardization

Abbreviation	Full Name
NES	Networked Energy Services
HES	Head End System
LT	Low Tension
HT	High Tension
MVA	Mega Volt Ampere
AT&C	Aggregate Technical and Commercial
ISGW	India Smart Grid Week
BPL	Broadband Over Power Line
NFC	Near Field Communications
CPE	Consumer Premises Equipment
IEEE	Institute of Electrical and Electronic Engineers
LTE	Long Term Evolution
ISM	Industrial, Scientific and Medical
OFDM	Orthogonal Frequency Division Multiplexing
GFSK	Gaussian Frequency Shift Keying
BFSK	Binary Frequency Shift Keying
OQPSK	Offset Quadrature Phase Shift Keying
ASK	Amplitude Shift Keying
FAN	Field Area Network
HAN	Home Area Network
WMAN	Wireless Metropolitan Area Network
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WNAN	Wireless Neighbourhood Area Network
P2P	Point to Point
WAVE	Wireless Access in Vehicle Environment

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