

ISGF White Paper

Additional Spectrum for Low Power RF Communications for M2M, IoT, IoE Devices in Smart Cities

India is taking massive steps towards the goal of ubiquitous connectivity in our lives and numerous Ministries and organisations in India have announced their plans of improving the quality of lives of the citizens. To make these objectives successful, adequate spectrum would be required for seamless communications. The current 865-867 MHz would not be sufficient to cater to the billions of M2M, IoT, IoE devices that would be deployed in smart cities. About 50-60% of such devices would be using low power RF communications in the sub-GHz bands. Based on comprehensive quantitative analysis, it is recommended to allocate 10-12 MHz for low power RF devices. Moreover, the channel spacing may be increased to 400 KHz (maximum) for minimising adjacent channel interference and yielding higher data rates.

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About India Smart Grid Forum

India Smart Grid Forum (ISGF) is a public private non-partisan initiative of the Ministry of Power (MoP), Government of India for accelerated development of smart grid technologies in the Indian power sector. ISGF was set up in 2010 to provide a mechanism through which academia, industry, utilities and other stakeholders could participate in the development of Indian smart grid systems and provide relevant inputs to the government's decision making.

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Abbreviations

IoT – Internet of Things
IoE – Internet of Everything
M2M – Machine to Machine
TEC – Telecommunication Engineering Center
DoT – Department of Telecommunications
NSGM – National Smart Grid Mission
MoUD – Ministry of Urban Development
DeitY – Department of Electronics and Information Technology
ISGF – India Smart Grid Forum
TSDSI – Telecommunication Standards Development Society, India
PLC – Power Line Carrier
RF – Radio Frequency
ISO – International Organisation for Standardisation
SCC – Smart Cities Council
ITU – International Telecommunication Union
GIS – Geographical Information System
UG – Under Graduate
PG – Post Graduate
PHD – Doctor of Philosophy
RWA – Residents Welfare Association
FDI – Foreign Direct Investment
FII – Foreign Institutional Investor
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
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

1. Introduction

Every one of us likes to have our smart phones, tablets, phablets etc. being seamlessly connected to the internet. With initiatives like Internet of Everything (IoE), Machine to Machine (M2M) Communications and Smart Cities, the number of ‘connected’ or ‘smart’ devices would exponentially increase. It is estimated that by 2020, there will be 50 billion connected devices and 7.6 billion humans on Earth. 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.

The objective of this Paper is to present a study on RF spectrum allocation for low power devices to enable the M2M/IoT/IoE /Smart Cities initiatives that India and the world have already embarked upon. TEC/DoT may consider the findings and recommendations mentioned in this report while formulating the next frequency allocation plan.

2. Machine to Machine, Internet of Things, Internet of Everything and Smart Cities

2.1 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)¹ 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 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 soon². 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)³ 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.

The Department of Electronics and Information Technology (DeitY) has released a draft policy on Internet of Things⁴ which envisages the creation of an Indian IoT Industry of USD 15 billion by 2020,

¹ http://indiansmartcities.in/downloads/CONCEPT%20NOTE-13-10-2014_mkgnew.pdf

² Office Memorandum of NSGM was issued on March 27, 2015

³ A Unit under the Department of Telecommunications (DoT)

⁴ [http://deity.gov.in/sites/upload_files/dit/files/Draft-IoT-Policy%20\(1\).pdf](http://deity.gov.in/sites/upload_files/dit/files/Draft-IoT-Policy%20(1).pdf)

undertaking capacity development for IoT specific skill sets, undertaking research and development for all assisting technologies and developing IoT products specific to Indian needs in all possible domains.

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.

Telecommunications Standards Development Society, India (TSDSI) is in the process of preparing technical reports containing use cases on various domains of Machine to Machine Communications/Internet of Things.

2.2 Global Scenario

Earlier this year, ISO has released a standard (ISO 37120⁶) 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 group⁸, '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.

3. ISGF Study on Smart Cities

ISGF has conducted a study on various domains of smart cities/IoT/IoE/M2M that has resulted in the following themes, domains and sub-domains that are expected to be important elements:

Broad Themes	Domains	Sub- Domains
PHYSICAL INFRASTRUCTURE	ENERGY	<ul style="list-style-type: none"> Electricity Renewable Energy Gas Other Fuels (cooking, heating, manufacturing etc.) Energy Efficiency
	WATER	<ul style="list-style-type: none"> Potable Water Non-Potable Water Industrial Water Agricultural Water Other Water Bodies (Ponds/Tanks/Lakes) Rivers and Canals

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>

	WASTE	<ul style="list-style-type: none"> • Hazardous Waste (Toxic/Reactive/Corrosive/Explosive) • E-Waste • Medical/Bio-medical Waste • Sanitation & Sewage • Radioactive Waste • Rain Water/Storm Water/Drainage • Municipal Solid Waste (Incl. Religious Waste)
	TRANSPORTATION	<ul style="list-style-type: none"> • Road/Rail/Metro/Tram/Multimodal • Water • Air • Electric Vehicles
	BUILDINGS & MARKETS	<ul style="list-style-type: none"> • Residential • Commercial • Industrial • Shopping Malls • Market Places/Mandis • E-Commerce Infrastructure • EV charging stations • Parking Lots
	COMMUNICATION	<ul style="list-style-type: none"> • Voice • Data (Incl. M2M & IoT/IoE) • Video • Post & Courier
	City Control Center	<ul style="list-style-type: none"> • Common Command and Control Room • Weather & Events Forecasting
INSTITUTIONAL INFRASTRUCTURE	GOVERNANCE TRANSPARANCY & ACCOUNTABILITY	<ul style="list-style-type: none"> • E-Governance • Service Delivery
	SECURITY	<ul style="list-style-type: none"> • Physical Security • Cyber Security • Policing • Surveillance
	EMERGENCY SERVICES	<ul style="list-style-type: none"> • Fire • Ambulance • Disaster Management
	ENFORCEMENT	<ul style="list-style-type: none"> • Policing
	PLANNING	<ul style="list-style-type: none"> • GIS • Modelling Tools • Data Collection and Analytics
	LEGAL	<ul style="list-style-type: none"> • Court • Legal Cells • Prison/Juvenile Centers
	ENVIRONMENT	<ul style="list-style-type: none"> • Environmental Sustainability
SOCIAL INFRASTRUCTURE	EDUCATION	<ul style="list-style-type: none"> • Primary Education • Higher Education • UGs/PGs/PHDs

		<ul style="list-style-type: none"> • Research Institution • E-learning • Adult Literacy Centers • Vocational Training
	HEALTH	<ul style="list-style-type: none"> • Primary Healthcare Centers • Super Specialty hospitals • Mobile Health care services • Emergency Health care services • Preventive Vaccination • Child Mortality rate • E-Healthcare
	RELIGIOUS AND CULTURE	<ul style="list-style-type: none"> • Public Parks • Recreation Clubs • Theater and Auditoriums • Places of Worship
	SPORTS RECREATION & ENTERTAINMENT	<ul style="list-style-type: none"> • Playgrounds/Gardens • Sports Academies/Training Centers • Training Centers
	INNOVATION	<ul style="list-style-type: none"> • Culture inspiring Innovation, Development of Clusters
		<ul style="list-style-type: none"> • RWAs • Complaint/Suggestion Review • Feedback Collection
	Citizen Advisory Committees	<ul style="list-style-type: none"> • Women/Children Welfare Bodies
ECONOMIC INFRASTRUCTURE	ECONOMY	<ul style="list-style-type: none"> • GDP • Job Creation • Incubation Centers • Government Institutions • Livelihood Activities • Market Growth
	FINANCE	<ul style="list-style-type: none"> • Banking • Micro Finance • FDI & FII Investors

Table 1: Themes, domains and sub-domains for IoE/M2M/Smart Cities

Source: ISGF White Paper on Smart Cities

Apart from this, smart agriculture and smart villages are some domains that will be part of the IoT/IoE/M2M initiative that India is envisaging.

3. Use Case for Low Power RF Technology

3.1 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 Application Areas

Out of above mentioned domains, low power RF communications could be used in the following domains:

Electricity (Grid) <ul style="list-style-type: none"> • 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) <ul style="list-style-type: none"> • Residential Buildings • Commercial Buildings • Industrial Buildings • Shopping Malls
Renewable Energy	EV Charging Stations
Gas	Parking Lots
Water Distribution: <ul style="list-style-type: none"> • Portable Water • Non-portable Water • Industrial Water • Agricultural Water • Other Water Bodies (Ponds, Lakes, Tanks etc.) 	Hospitals and E-Healthcare <ul style="list-style-type: none"> • Primary Healthcare Centres • Super Specialty Hospitals • E-Healthcare
Rivers and Canals – Monitoring and Management	Theater and Auditoriums
Waste Collection, Monitoring and Management <ul style="list-style-type: none"> • Hazardous Waste (Toxic/Reactive/Corrosive/Explosive) • E-Waste • Medical/Bio-Medical Waste • Sanitation and Sewage • Rain Water/Storm Water/Drainage • Radio Active Waste • Municipal Solid Waste (incl. Religious Waste) 	Places of worship
Sports Academies	Training Centres

Table 2: Domains and sub-domains that would use low power RF technology

3.3 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
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.

4. Current Scenario of the De-licensed Bands

4.1 The 433 to 434 MHz Band

As per the notification G.S.R. 680 (E), this frequency band was de-licensed in September 2012. The specifications require that the maximum effective radiated power and maximum channel bandwidth be 10mW and 10 KHz respectively. In addition to using an in-built antenna, the devices (that operate on this frequency band) are meant for indoor applications only. Currently, there are very few devices in this band.

4.2 The 865 to 867 MHz Band

As per the notification G.S.R. 168 (E), this frequency band was de-licensed in March 2005. The specifications require that the maximum transmitted power, maximum effective radiated power and maximum channel bandwidth be 1 W, 4 W and 200 KHz respectively. This band can be used for Radio Frequency Identification (RFID) or any other low power wireless devices or equipment.

Currently this band is not congested as M2M/IoT/Smart cities initiatives are still gathering pace. However, with introduction of more and more devices, this frequency band may not remain adequate to meet the expected demand.

4.3 The 2.4 to 2.4835 GHz Band

As per the notification G.S.R. 45 (E), this frequency band was de-licensed in January 2005. The specifications require that the maximum transmitted power, maximum effective radiated power and maximum antenna height be 1 W (in a spread of 10 MHz or higher), 4 W and within 5 meters above the roof-top of an existing authorized building respectively. This band can be used for any wireless equipment or device.

At present, too many devices use this frequency band. These include (but are not limited to) Wi-Fi and Bluetooth devices, microwave ovens, cordless phones etc. High interference, limited range and high power consumption (of the devices) limit the use of this band for M2M/IoT/Smart Cities.

4.4 The 5.150 to 5.350 GHz Band and 5.725 to 5.875 GHz Band

As per G.S.R. 46 (E), these frequency bands were de-licensed in January 2005. The specifications require that the maximum mean effective isotropic radiated power and maximum mean effective isotropic radiated power density be 200 mW and 10 mW/MHz respectively in any 1 MHz band. In addition, the antenna must be in-built or indoor. This band can be used for indoor applications only. These include usage within the single contiguous campus of an individual, duly recognized organization or institution.

Although this frequency band offers low interference, it is not widely used in today's scenario.

4.5 The 5.825 to 5.875 GHz Band

As per the notification G.S.R. 38 (E), this frequency band was de-licensed in January 2007. The specifications require that the maximum transmitted power and the maximum effective isotropic radiated power be 1 W (in a spread of 10 MHz or higher) and 4 W respectively. This band can be used for any wireless equipment or device.

This frequency band also offers low interference, but will not be ideal for low power applications due to relatively high power consumption and limited range. However this band could be used for point to point and point to multipoint links.

The following table summarises the above mentioned specifications:

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) Maximum effective radiated power: 4W Maximum antenna height: 5 metres above the roof-top of an existing authorised building	Nothing specified.	Any low power device or equipment.
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.

Table 3: Summary of Specifications of de-licensed bands

5. 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 IoT/loE/M2M/Smart Cities initiatives.

The following table shows wireless frequency spectrum allocation in some countries/regions:

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

Table 4: Global frequency spectrum allocation scenario

6. 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-licensed 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, India would not be able to cater to the millions and billions of devices that would be installed in the IoT/M2M/Smart Cities initiatives.

If we adopt a reactive approach and allocate additional spectrum after network congestion leads to large scale projects not being successful, 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 un-licensed spectrum.

7. A Snapshot of the Top Contenders

The 400 MHz bands and 800 MHz bands are top contenders for allocating additional frequency bands. The table below throws more into the current scenario of spectrum allocation in these bands:

(The un-licensed bands are highlighted.)

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.

Table 5: Indian scenario of frequency allocation in 400 MHz, 800 MHz and 900 MHz bands

8. Quantitative Analysis

In this section, a detailed analysis for different technical parameters is considered for effective spectrum allocation.

8.1 Frequency Band

One Unit Cell Definition:

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 up or as high as 7 Sq Km.

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

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 Km⁹. (Kolkata Metropolitan Area had a total population of 14,035,959¹⁰ living in 1,886.67.41 Sq Km¹¹). 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 devices¹² 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.

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

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

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

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

Please note that the above said band is required if all M2M/IoT/IoE devices are using the sub-GHz bands. But in practice, different vendors/users might use different technologies occupying different frequency bands or may even use wired media for communications. As a conservative estimate, atleast 50-60% of the connected devices will use low power RF communications. Hence instead of allocating 20 MHz or 20.8 MHz, **India would require 10-12 MHz to cater to billions of M2M/IoT/IoE devices in a smart city.**

8.2 What can be achieved in the existing 2 MHz band (865-867 MHz band)?

Based on the same assumptions and calculations mentioned in section 8.1, 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): $66,667 \text{ bits } [= 1/(15 \times 10^{-6})]$
= 8,333 Bytes per second

In 60 seconds we can transmit in one channel : 5, 00,000 Bytes

Number of packets (150 Byte 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 2MHz 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.

9. Recommendations

Based on the quantitative analysis mentioned in Section 8 and considering the global scenario, below are some recommendations for India.

9.1 Frequency Band

The analysis done in Section 8 is considering all M2M/IoT/IoE devices will use the same frequency band. But in practice, different vendors/users might use different technologies occupying different frequency bands or may even use wired media for communications.

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.

Looking at all explained above, it is recommended to provide a frequency band in the range of 10-12MHz. 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).

9.2 Frequency Band Selection

It is pertinent to mention that 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). The current usage of PMRTS and CMRTS needs to be examined in order to find out how much spectrum can be freed. Some spectrum earmarked for PMRTS and CMRTS may be freed and allocated for low power RF devices for M2M/IoT/IoE devices in India. It will be preferable if the additional spectrum is allotted closer to the current de-licensed band of 865-867 MHz.

9.3 Channel Separation

It is recommended to provide a better 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.