EEM602 Internet of Things

Lecture # 3
IoT Connectivity Technologies

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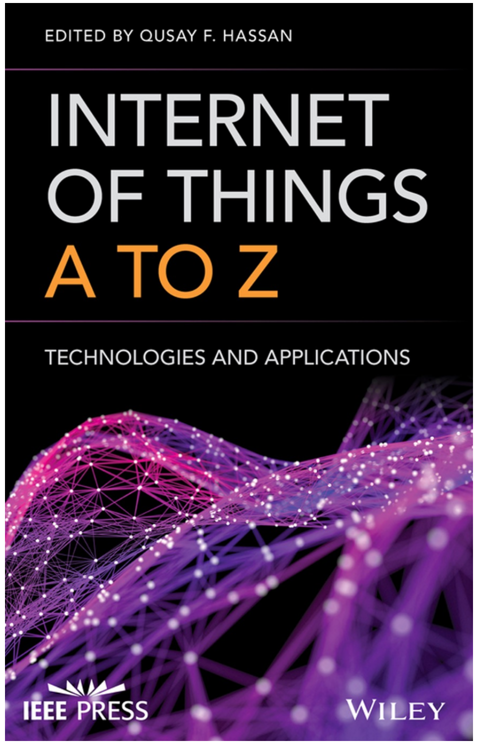
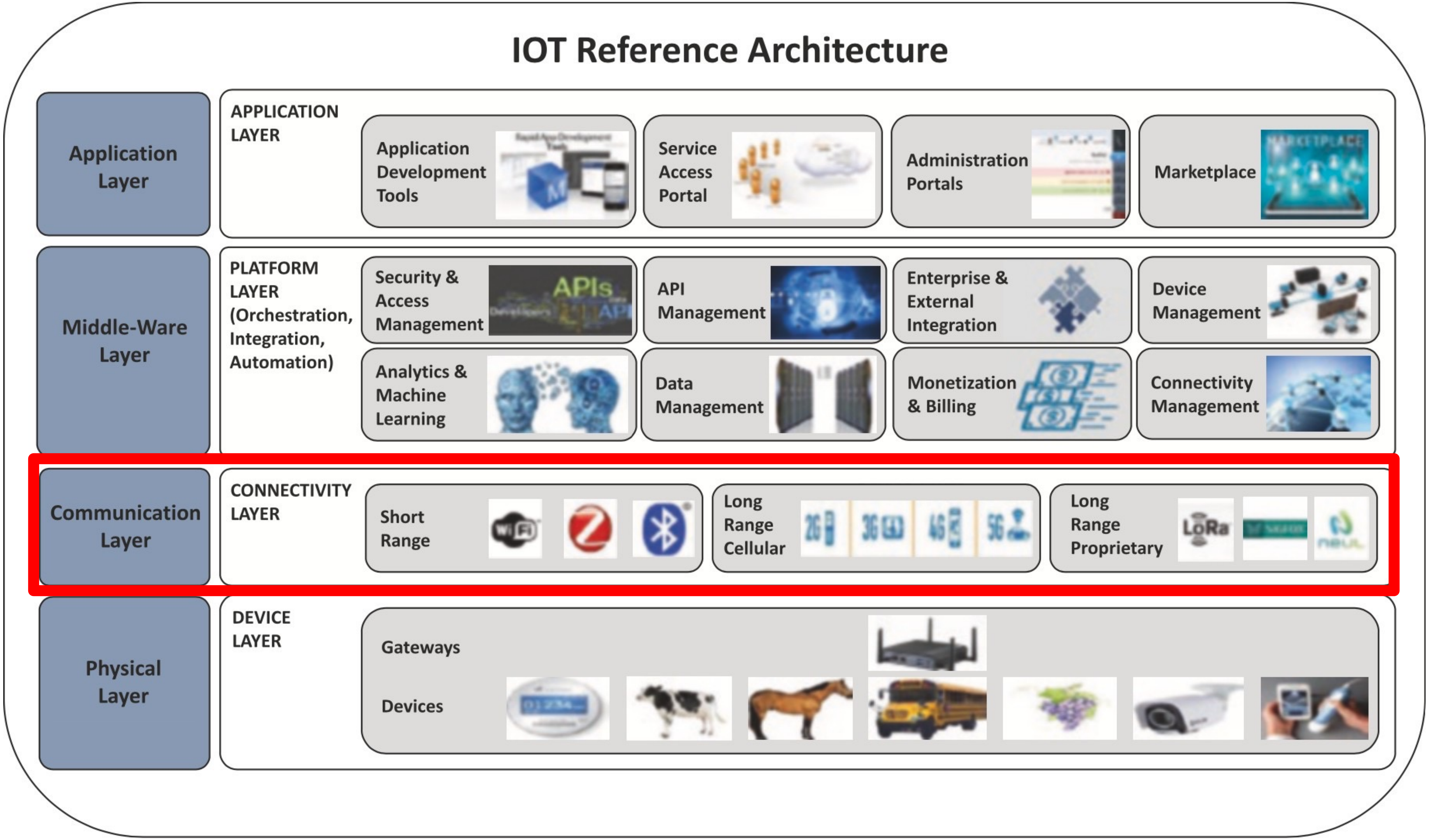
An Overview of Enabling Technologies for the Internet of Things


EDITED BY QUSAY F. HASSAN
INTERNET OF THINGS A TO Z
TECHNOLOGIES AND APPLICATIONS
IEEE PRESS
WILEY


IOT Reference Architecture
Application Layer
APPLICATION LAYER
Application Development Tools
Service Access Portal
Administration Portals
Marketplace
Middle-Ware Layer
PLATFORM LAYER (Orchestration, Integration, Automation)
Security & Access Management
API Management
Enterprise & External Integration
Device Management
Analytics & Machine Learning
Data Management
Monetization & Billing
Connectivity Management
Communication Layer
CONNECTIVITY LAYER
Short Range
Long Range Cellular
Long Range Proprietary
Physical Layer
DEVICE LAYER
Gateways
Devices

- After a node has been identified (i.e., addressed and named), it can start communicating with other nodes or with backend servers.

- However, this communication requires the selection of a suitable communication medium, which depends on the capabilities of the node (e.g., power and coverage).

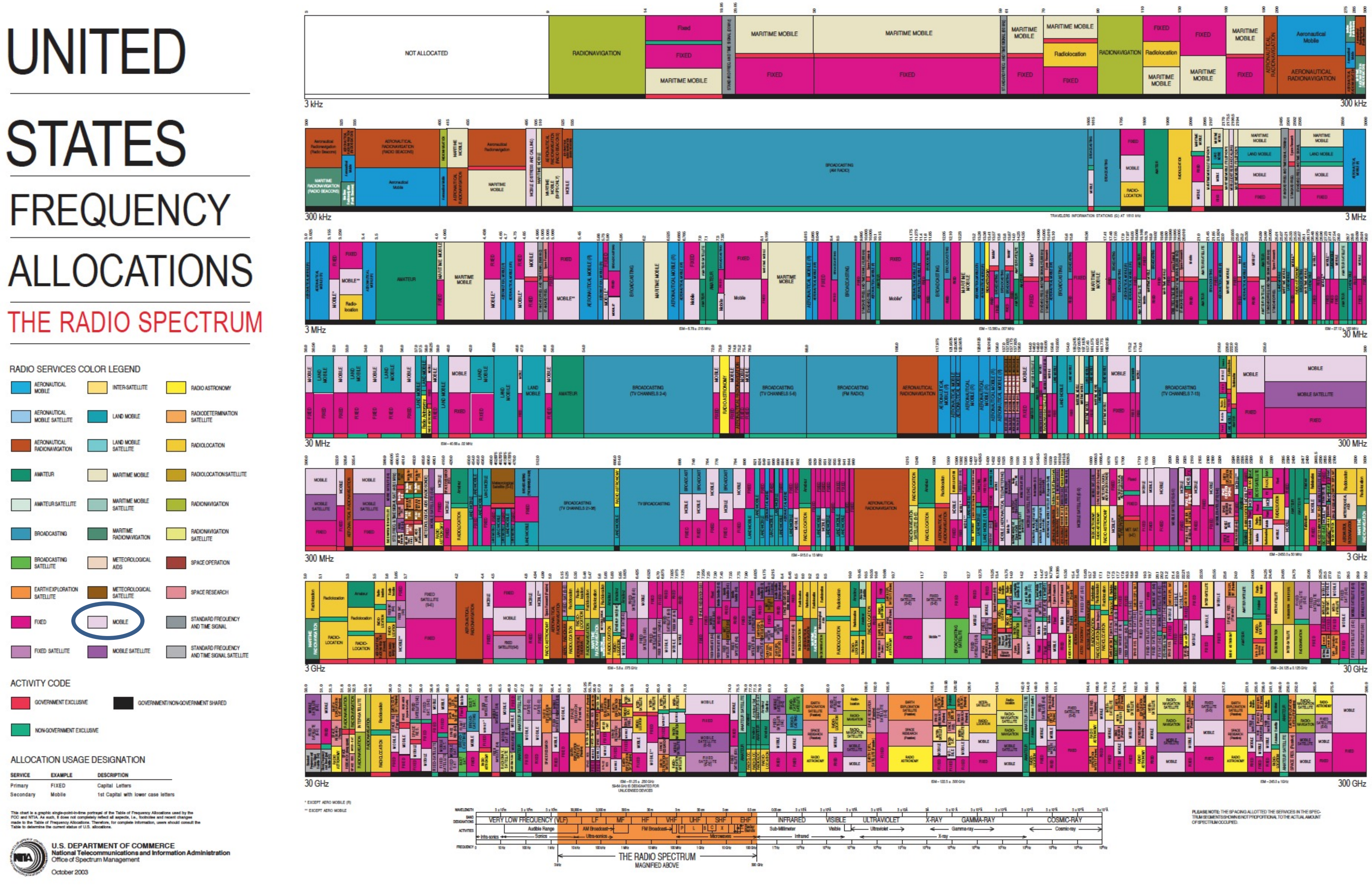
- Nodes can communicate horizontally (i.e., ad hoc with another node) or vertically (i.e., with servers in the middleware layer).

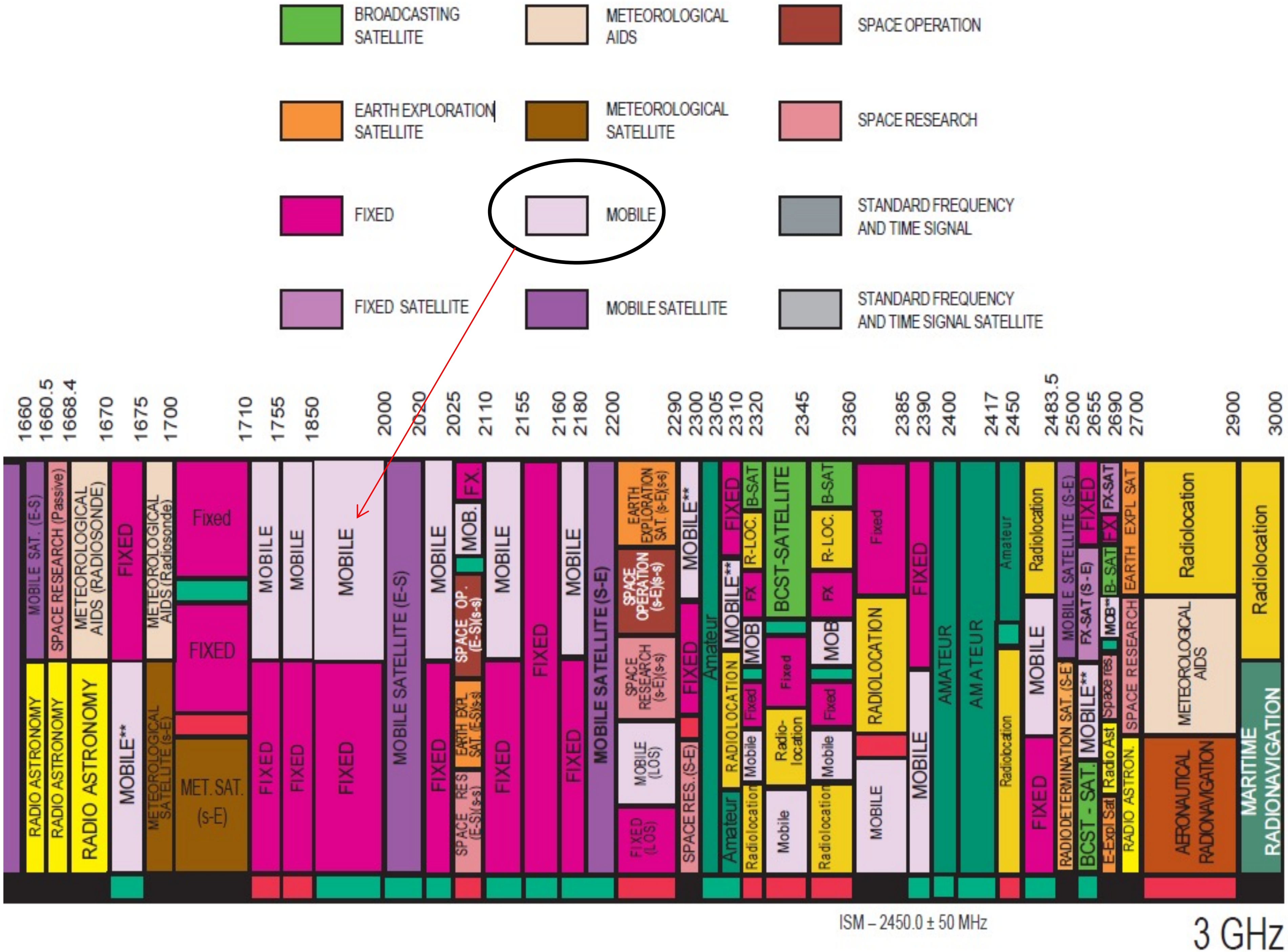
- Communication technologies are discussed in this Lecture with emphasis on their use in the IoT. These commonly employed technologies are listed in ascending order based on their wireless range (i.e., wired and short, medium, and long range):

Wireless Communications Technologies for IoT

1. PLC , X10
2. NFC / RFID
3. Bluetooth
4. Zigbee / Z-wave / 6LOWPAN
5. Wireless LAN, WIFI
6. Wireless MAN, WIMAX
7. LORA / LORAWAN
8. NB-IOT and LTE-M
9. Cellular phone

Very Crowded RF spectrum





BROADCASTING SATELLITE
METEOROLOGICAL AIDS
SPACE OPERATION
EARTH EXPLORATION SATELLITE
METEOROLOGICAL SATELLITE
SPACE RESEARCH
FIXED
MOBILE
STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE
MOBILE SATELLITE
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
1660
1660.5
1668.4
1670
1675
1700
1710
1755
1850
2000
2020
2025
2110
2155
2160
2180
2200
2290
2300
2305
2310
2320
2345
2360
2385
2390
2400
2417
2450
2483.5
2500
2655
2690
2700
2900
3000
ISM – 2450.0 ± 50 MHz
3 GHz

TABLE 1.1 Frequency Band Designations

Frequency range, GHz	Band designati
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	µm

By: Dr.Mohab Mangoud

Table 3.1 Comparison of communication technologies.

Technology	Data rate	Range	Mobility	Security	Ad hoc	Native TCP/IP	Header size	Latency	Frequency	Scalable
X10	20 bps	~20 m	No	No	Yes	No	8 bytes	Low	120 KHz	No
PLC	10 Mbps	~ 9 km	No	No	Yes	Yes	133 bytes	Varies	Narrowband (3–500 KHz) Broadband (1.8–250 MHz)	Yes
NFC	106, 212, 424, and 848 kbps	~20 cm	Yes	LPI/D[a)]	Yes	No	4 bytes	Low	13.56 MHz	No
UWB	480 Mbps–1.6 Gbps	~10 m	Yes	LPI/D	Yes	Yes	40 bits	Low	3.1–10.6 GHz	Yes
Z-Wave	9.6, 40, and 100 kbps	~30 m	Yes	No	Yes	No	Varies	Low	Regional sub-GHz bands	Yes
Thread	40–250 kbps	~30 m	Yes	TLS 1.2	No	No	40 bytes	Low	Global 2.4 GHz	Yes
MiWi	250 kbps	~20–50 m	Yes	TLS 1.2	Yes	No	11 bytes	Low	Regional sub-GHz and global 2.4 GHz	Yes
BLE	1 Mbps	~50 m	Yes	AES 128-bit	Yes	No	2 bytes	Low	Global 2.4 GHz	No
ANT+	1 Mbps	~50 m	Yes	AES 128-bit	Yes	No	14 bytes	Low	Global 2.4 GHz	Yes
Wi-Fi	250 Mbps	~60 m	Yes	WPA2 with AES	Yes	Yes	2 bytes	Low	Global 2.4, 5.8 GHz	Yes
ZigBee	20, 40, and 250 kbps	~100 m	Yes	128-bit Encryption	Yes	No	15 bytes	Low	Regional sub-GHz and global 2.4 GHz	Yes
ISA100.11a	250 kbps	~200 m	Yes	AES 128-bit	Yes	No	Varies	Low	Global 2.4 GHz	Yes
WirelessHART	250 kbps	~200	Yes	AES-128 bit	Yes	No	21 bytes	Low	Global 2.4 GHz	Yes

Wi-Fi	11 Mbps, 54 Mbps, 600 Mbps, 1300 Mbps, and 6.9 Gbps	~200 m	Yes	WPA2 with AES	Yes	Yes	2,346 bytes	High	Global 2.4, 5.8 GHz	Yes
D7A	167 kbps	1–5 km	Yes	AES 128-bit	Yes	No	3–38 bytes	Low	433 MHz, 868 MHz, 915 MHz	Yes
Sigfox	100 bps up, 600 bps down	~15 km	Yes	No	No	No	Varies	High	Regional sub-GHz bands	Yes
LoRa	0.3–50 kbps	~13 km	Yes	128-bit encryption	Yes	No	Varies	Low	Regional sub-GHz bands	Yes
3G	144–400 kbps (while moving)	Vary	Yes	KASUMI[b)]	Yes	No	Varies	Medium	UMTS 850 MHz–2100 MHz	Yes
4G	Up to 1 Gbps	Vary	Yes	Enhanced SNOW 3G[c)]	Yes	No	Varies	Low	LTE bands	Yes
Weightless-W	1–10 Mbps	~5 km	Yes	128-bit encryption	Yes	No	10 bytes or more	High	TVWS	Yes

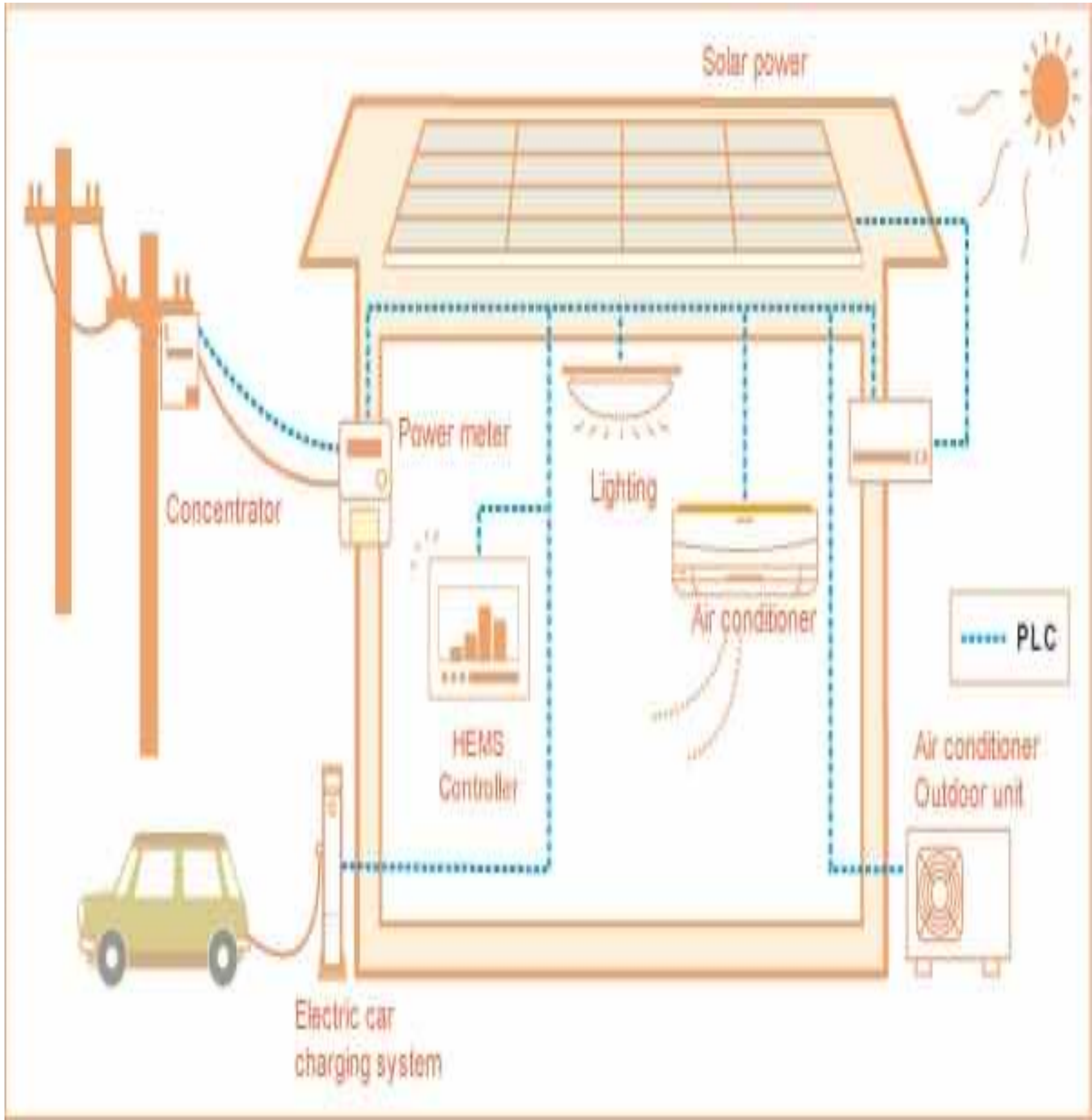
a) Low Probability of Intercept/Detect (LPI/D) is a set of wireless security techniques that allow devices to see but not to be seen by modern and capable intercept receivers.

b) KASUMI is a block cipher with a 128-bit key and 64-bit input and output.

c) SNOW 3G is a word-based synchronous stream cipher.

1. Power-Line Communication (PLC).

- This comprises a set of communication protocols that use power-line wiring to simultaneously transmit both data and alternating current.
- Using this approach, a person can power devices and control/retrieve data using only the standard power cables that run to the device.
- It is mainly preferable in stationary nodes because they rely on power lines
- *X10.* Similar to PLC, X10 is an industry standard that uses electrical cabling for signaling and controlling devices



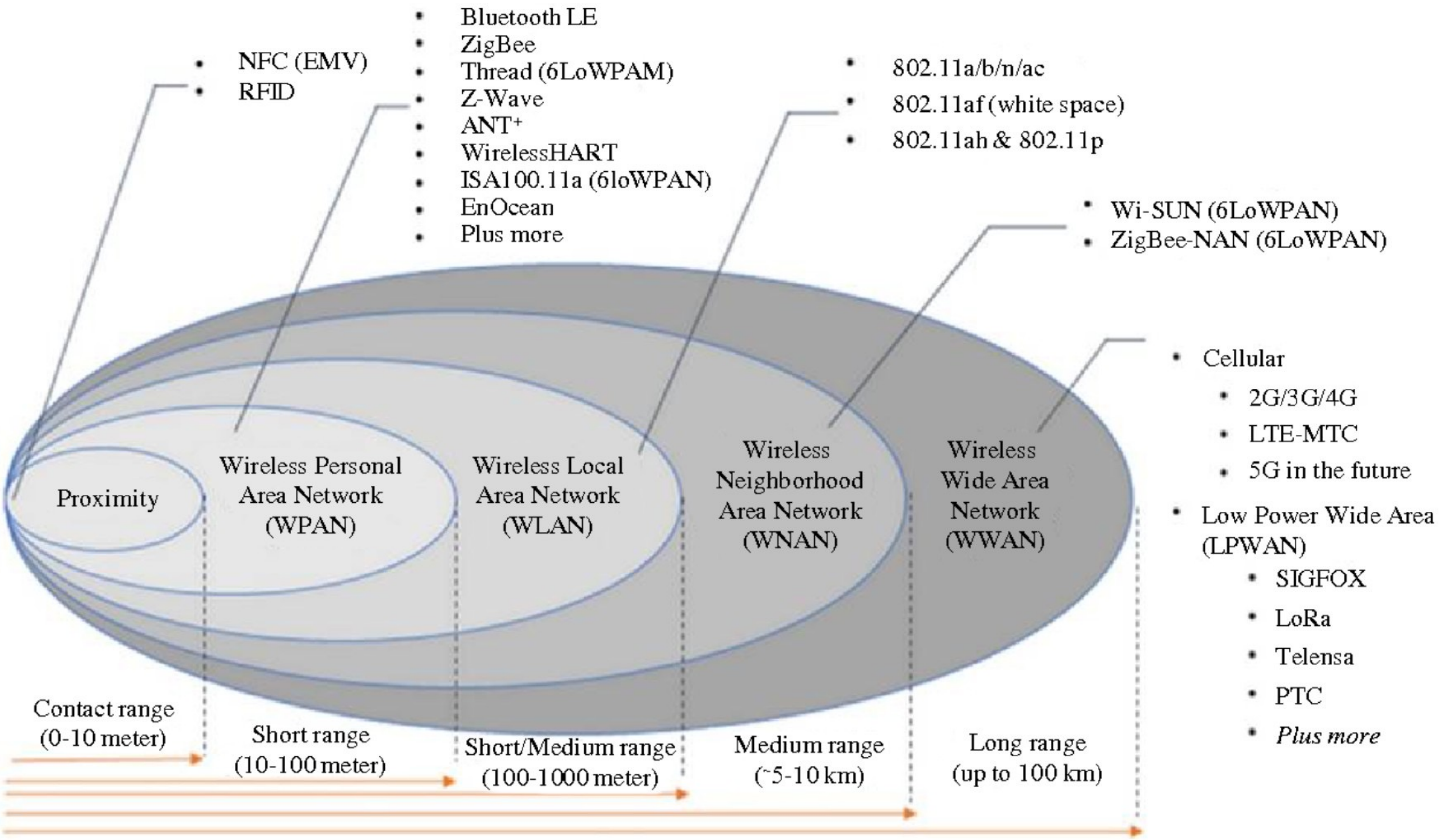
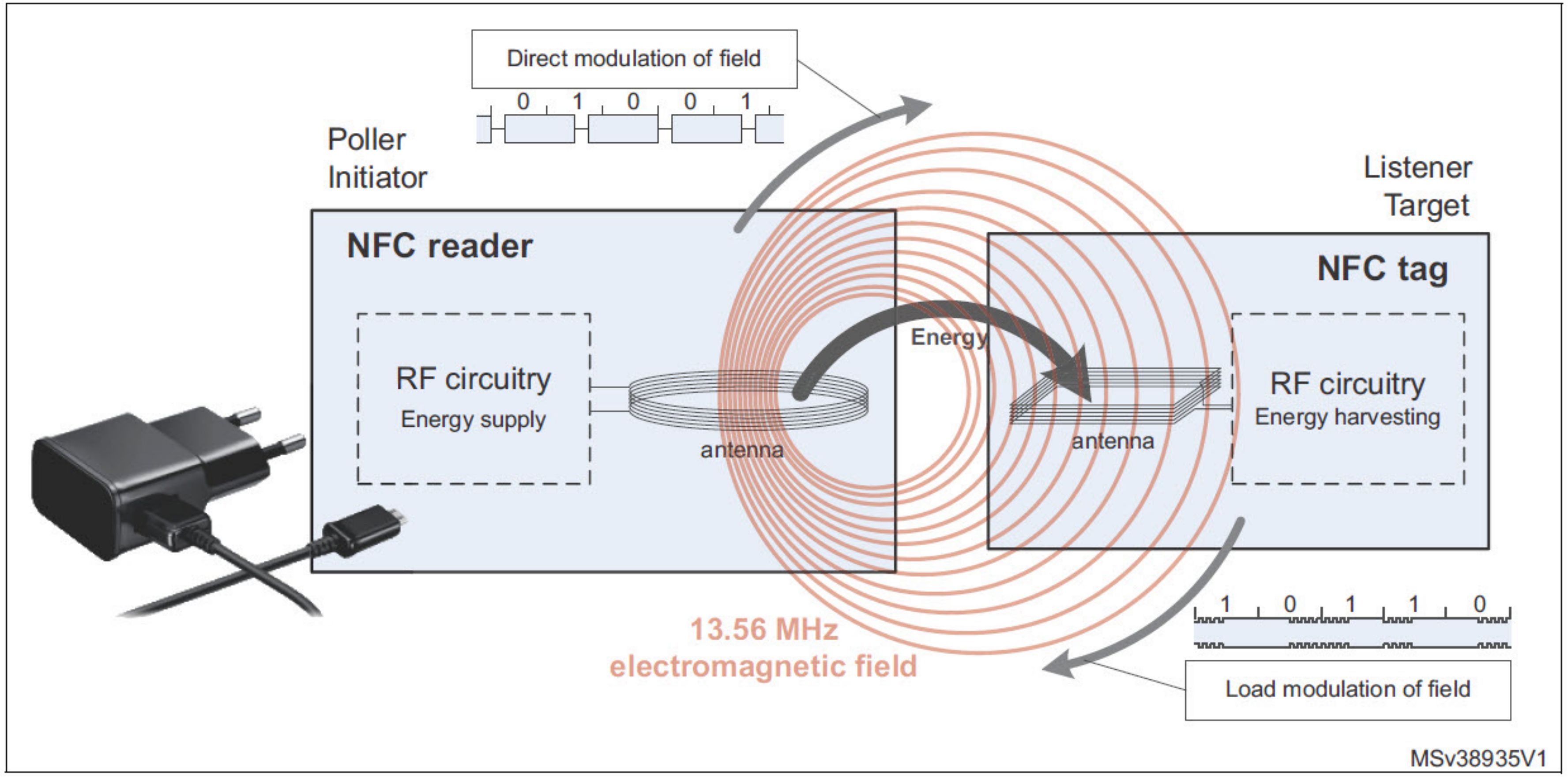


Figure 4. Wireless IoT connectivity technologies.

2. Near-Field Communication (NFC)

- A set of protocols that enable commu-nication between two devices over very short distances.

- NFC is employed in many IoT applications such as smart payments and access control systems.



- An active device can read data from an NFC tag by generating a radio wave using the 13.56 MHz carrier frequency.

https://www.microcontrollertips.com/programming-automation-using-nfc-tags-faq/

2. RFID

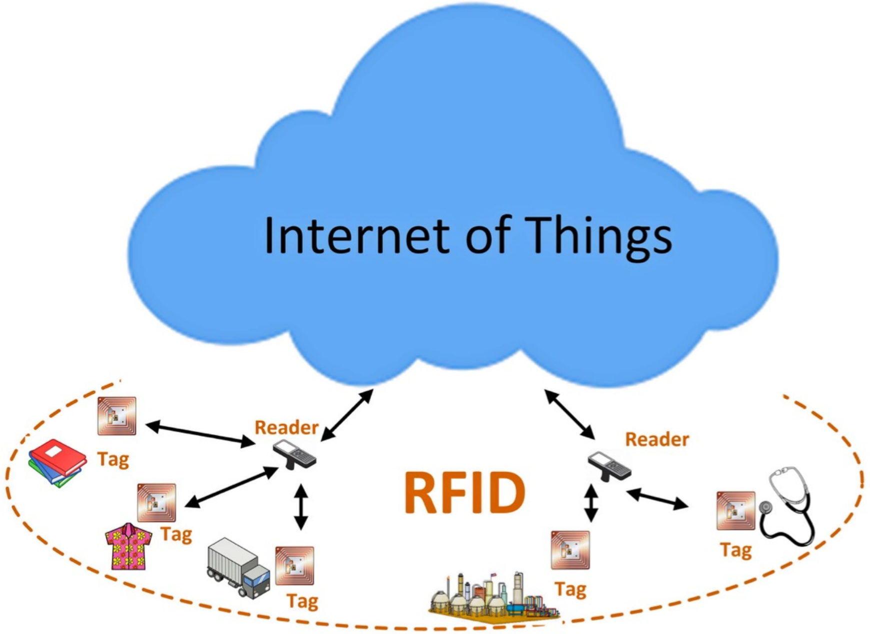


Figure 5.1 Data acquisition for the IoT through RFID.

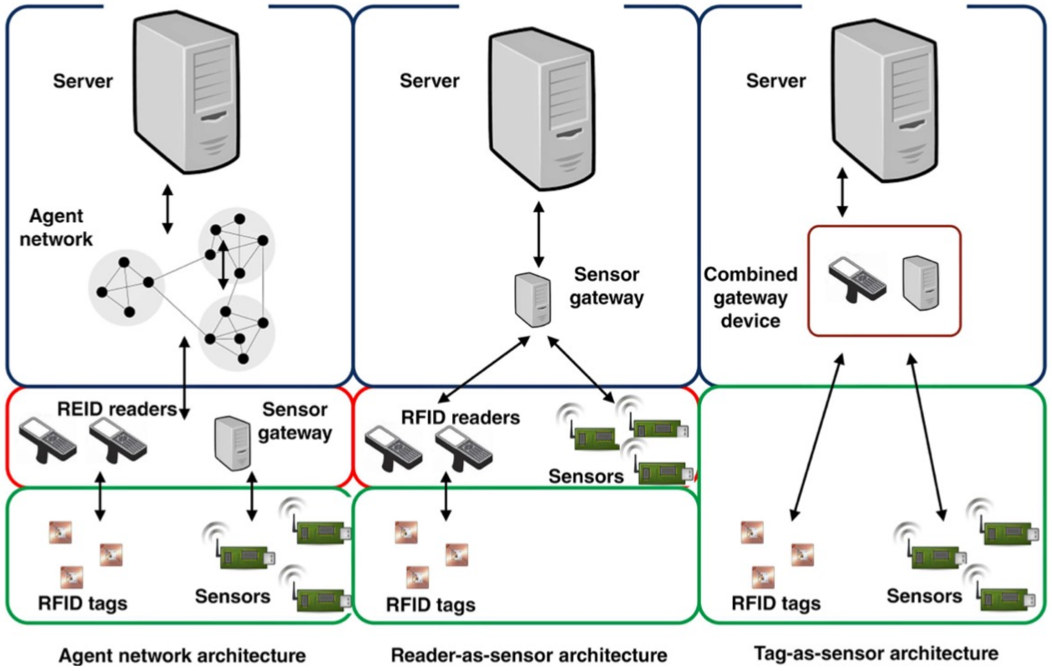
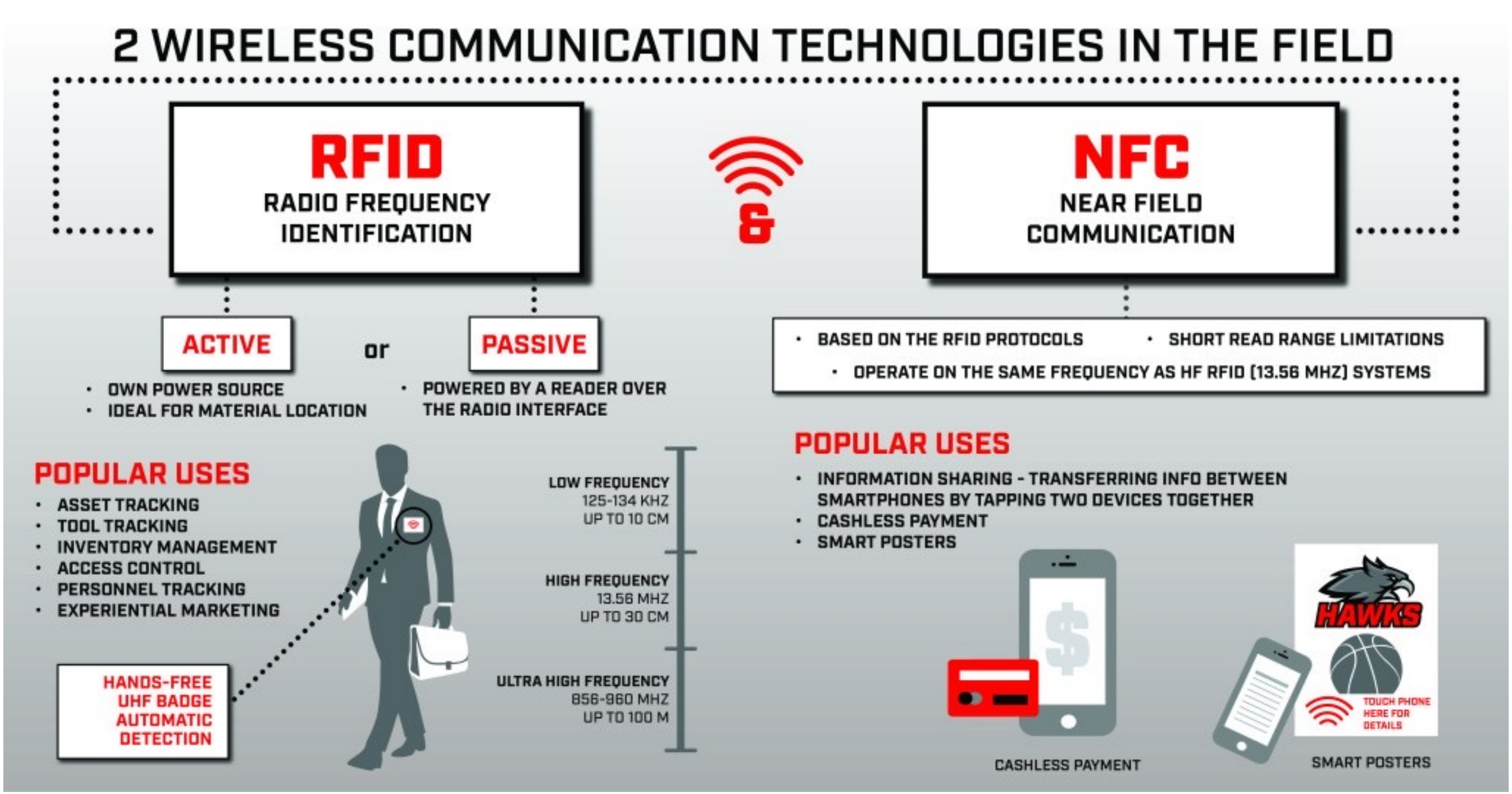


Figure 5.2 Network topologies for linking RFID sensors to the Internet.

RFID in the Internet of Things (Chapter 5 : Text book)

Akaa Agbaeze Eteng,1 Sharul Kamal Abdul Rahim,2 and Chee Yen Leow2
1Department of Electronic and Computer Engineering, University of Port Harcourt, Port Harcourt, Nigeria
2Wireless Communication Centre, Universiti Teknologi Malaysia, Johor, Malaysia


2 WIRELESS COMMUNICATION TECHNOLOGIES IN THE FIELD
RFID
RADIO FREQUENCY IDENTIFICATION
&
NFC
NEAR FIELD COMMUNICATION
ACTIVE
or
PASSIVE
• OWN POWER SOURCE
• IDEAL FOR MATERIAL LOCATION
• POWERED BY A READER OVER THE RADIO INTERFACE
POPULAR USES
• ASSET TRACKING
• TOOL TRACKING
• INVENTORY MANAGEMENT
• ACCESS CONTROL
• PERSONNEL TRACKING
• EXPERIENTIAL MARKETING
HANDS-FREE UHF BADGE AUTOMATIC DETECTION
LOW FREQUENCY
125-134 KHZ
UP TO 10 CM
HIGH FREQUENCY
13.56 MHZ
UP TO 30 CM
ULTRA HIGH FREQUENCY
856-960 MHZ
UP TO 100 M
• BASED ON THE RFID PROTOCOLS
• SHORT READ RANGE LIMITATIONS
• OPERATE ON THE SAME FREQUENCY AS HF RFID (13.56 MHZ) SYSTEMS
POPULAR USES
• INFORMATION SHARING - TRANSFERRING INFO BETWEEN SMARTPHONES BY TAPPING TWO DEVICES TOGETHER
• CASHLESS PAYMENT
• SMART POSTERS
$
HAWKS
TOUCH PHONE HERE FOR DETAILS
CASHLESS PAYMENT
SMART POSTERS

NFC IS A SUBSET OF RFID

ITEM CENTRIC

- **Invented in the 1980's**
- **Improves upon printed barcodes**
  - Does not require line of sight
  - Increased read range
  - Can be read quickly in batches
- **Stores and transmits simple ID's**
- **Inventory tracking through the supply chain**
- **Loss prevention**

Time to connect: <1ms

Read Range:
(passive) 1m-10m
(active) 10m-100m

Tag Reader:
Fixed infrastructure reader
Handheld reader

Tag Price: <$0.10

USER CENTRIC

- **Invented in 2002**
- **Improves upon QR codes**
  - Does not require line of sight
  - Increased security
  - Added intelligence
- **Stores and transmits multiple data types**
- **Adds utility to products during use**
- **Product authentication**

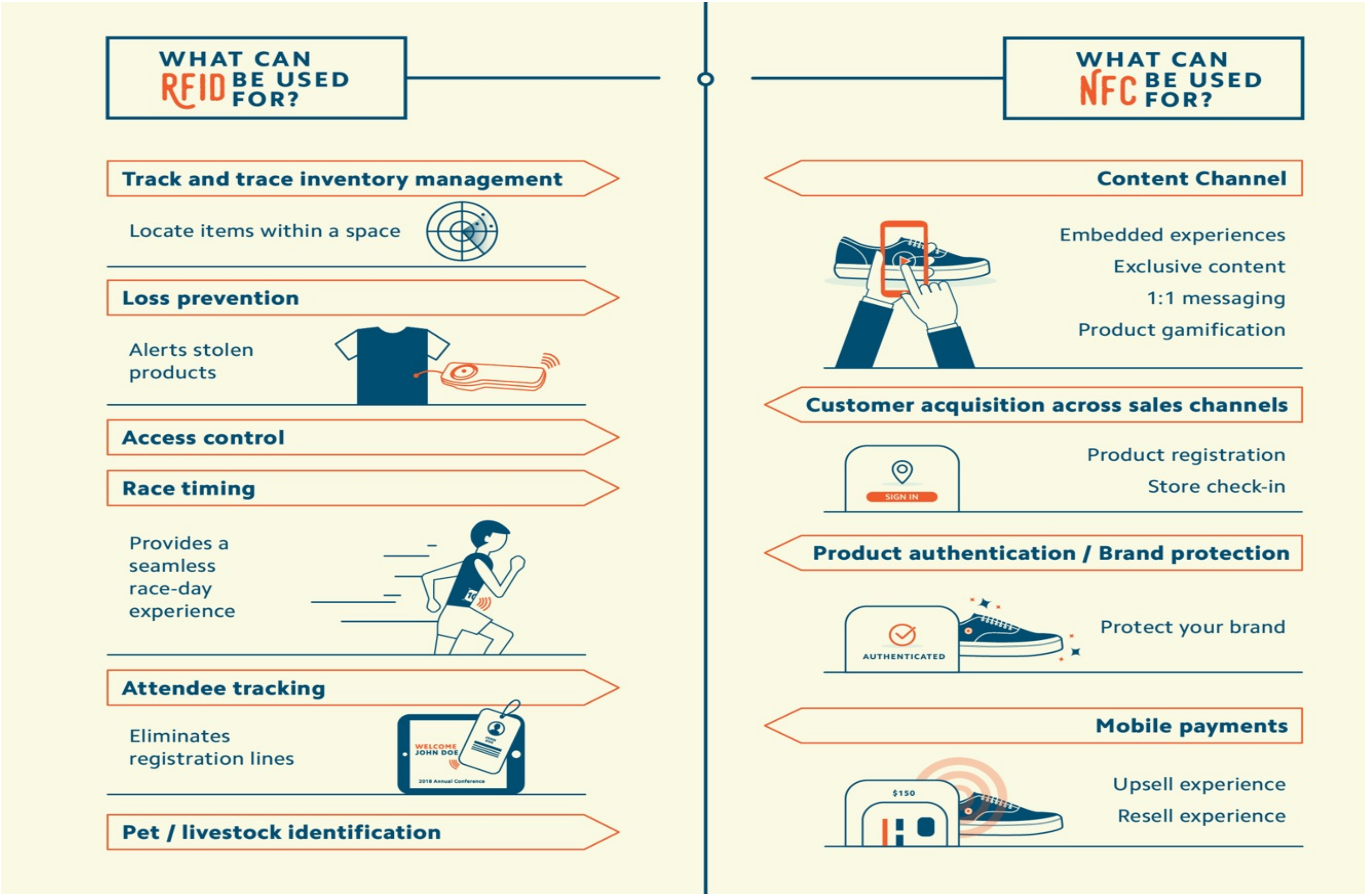
Time to connect: <1ms

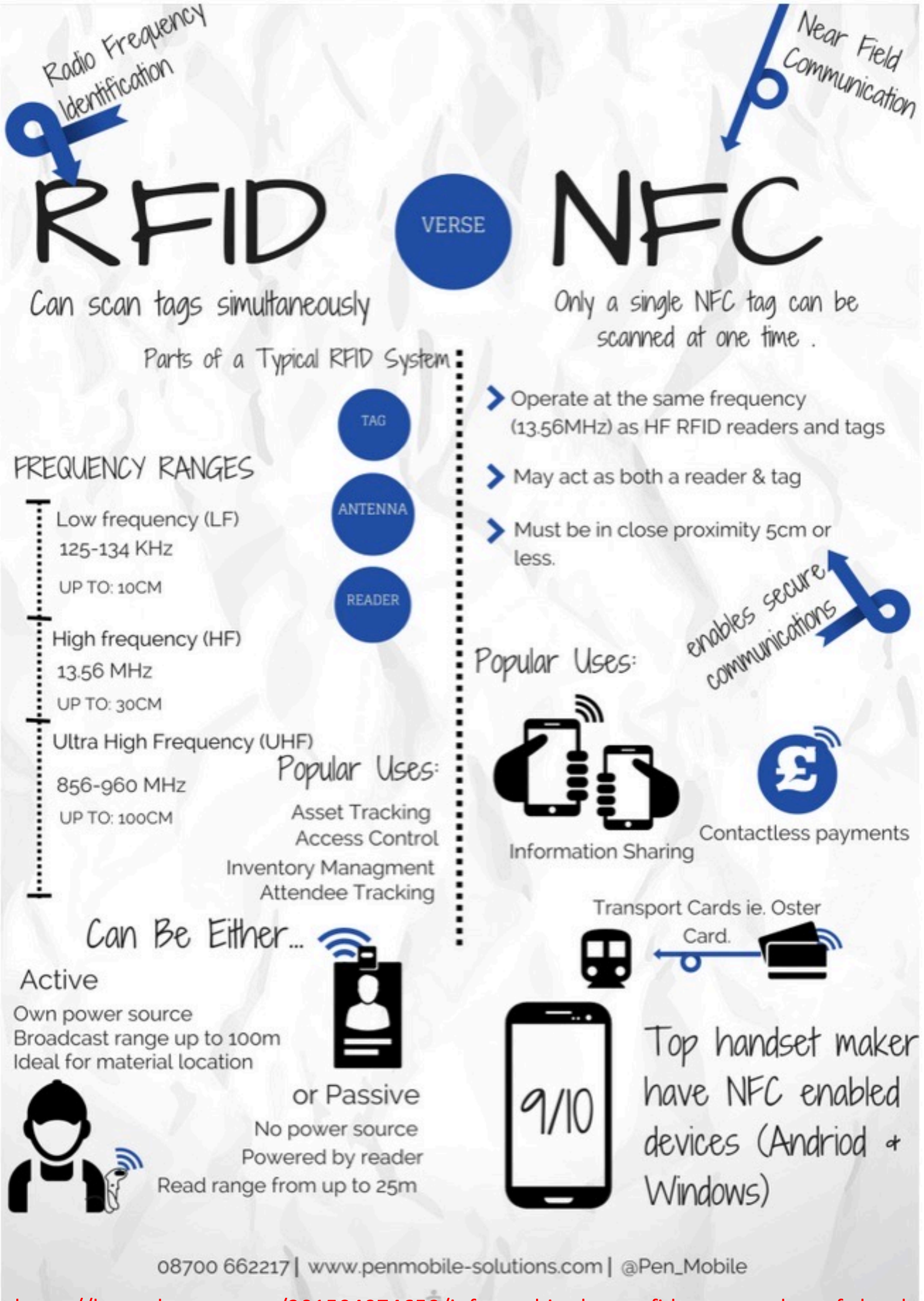
Read Range: 0cm-10cm

Tag Reader: Smartphone

Tag Price: <$0.10

https://www.bluebite.com/nfc/rfid-vs-nfc


WHAT CAN RFID BE USED FOR?
Track and trace inventory management
Locate items within a space
Loss prevention
Alerts stolen products
Access control
Race timing
Provides a seamless race-day experience
Attendee tracking
Eliminates registration lines
WELCOME JOHN DOE
2018 Annual Conference
Pet / livestock identification
WHAT CAN NFC BE USED FOR?
Content Channel
Embedded experiences
Exclusive content
1:1 messaging
Product gamification
Customer acquisition across sales channels
SIGN IN
Product registration
Store check-in
Product authentication / Brand protection
AUTHENTICATED
Protect your brand
Mobile payments
$150
Upsell experience
Resell experience



https://barcodenews.com/201504074650/infographic-shows-rfid-compared-to-nfc.html

4. Bluetooth

- A wireless standard is intended to exchange data over short distances and build *personal area networks* (PANs).

- For Bluetooth v4.0 and later versions, the energy consumption is improved, which renders Bluetooth well suited for sensors and other small devices that require low power.

- Internet-enabled nodes often use BLE to act with local nodes and send collected data to the backend for more actions.

- BLE can be used in an extensive range of applications, such as smart buildings, smart transportation, and wearables.

Bluetooth

- Bluetooth Low Energy (BLE)
- Beacons
- Direction Finding
- Mesh

	Bluetooth 2.1	Bluetooth 4.0 (LE)	Bluetooth 5.0 (LE)
Range	100 meters	100 meters	400 meters
Max range (free space)	100 meters	100 meters	1000 meters
Data Rate	1-3 Mbps	1 Mbps	2 Mbps
Application Throughput	0.7-2.1 Mbps	Up to 305 kbps	Up to 1.36 Mbps
Topologies	Point-to-Point	Point-to-Point, Broadcast	Point-to-Point, Broadcast, Mesh

Bluetooth

The **IEEE 802.15.1a** Standard evolved after vendors created Bluetooth technology as a short-distance wireless connection technology.

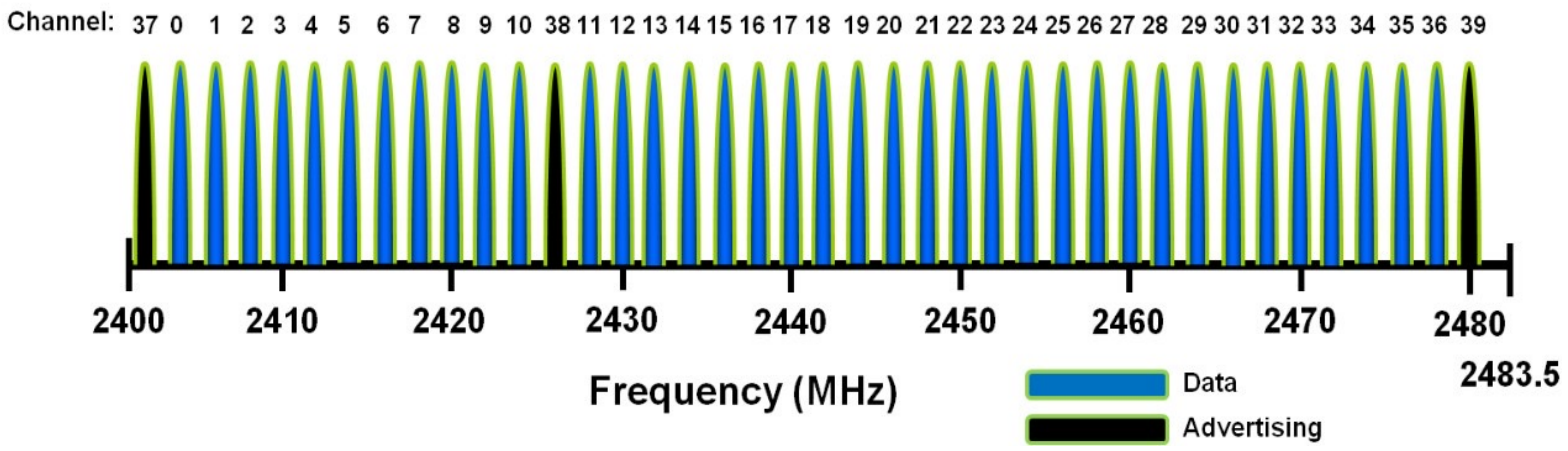
The characteristics of the Bluetooth technology are:

- Wireless replacement for cables (e.g., headphones or mouse)
- Uses 2.4 GHz frequency band
- Short distance (up to 5 meters, with variations up to 10 or 50 meters)
- Device is either master or slave
- Master grants permission to slave
- Data rate is up to 721 Kbps

Standard	Purpose
802.15.1a	Bluetooth technology (1 Mbps; 2.4 GHz)
802.15.2	Coexistence among PANs (noninterference)
802.15.3	High rate PAN (55 Mbps; 2.4 GHz)
802.15.3a	Ultra Wideband (UWB) high rate PAN (110 Mbps; 2.4 GHz)
802.15.4	Zigbee technology – low data rate PAN for remote control
802.15.4a	Alternative low data rate PAN that uses low power

Frequency Bands

The radio uses the 2.4 GHz Industrial, Scientific, and Medical (ISM) band to communicate and divides this band into 40 channels on 2 MHz spacing from 2.4000 GHz to 2.4835 GHz, starting at 2402 MHz:



	RFID	NFC	Bluetooth
Network type	Point-to-point	Point-to-point	WPAN
Communication	Unidirectional	Bidirectional	Bidirectional
Security	Hardware and protocol level	Hardware and protocol level	Protocol level
Range	Up to 100 m	<0.2 m	~100 m (class 1)
Frequency	LF/HF/UHF/Microwave	13.56 MHz	2.4–2.5 GHz
Bit rate	Varies with frequency	Up to 424 kbit/s	2.1 Mbit/s
Set-up time	<0.1 s	<0.1 s	<6 s
Power consumption	Varies with frequency	<15 mA	Varies with class
Continuous sampling	No	Yes	Yes

https://www.researchgate.net/figure/RFID-vs-NFC-vs-Bluetooth_tbl1_231212227

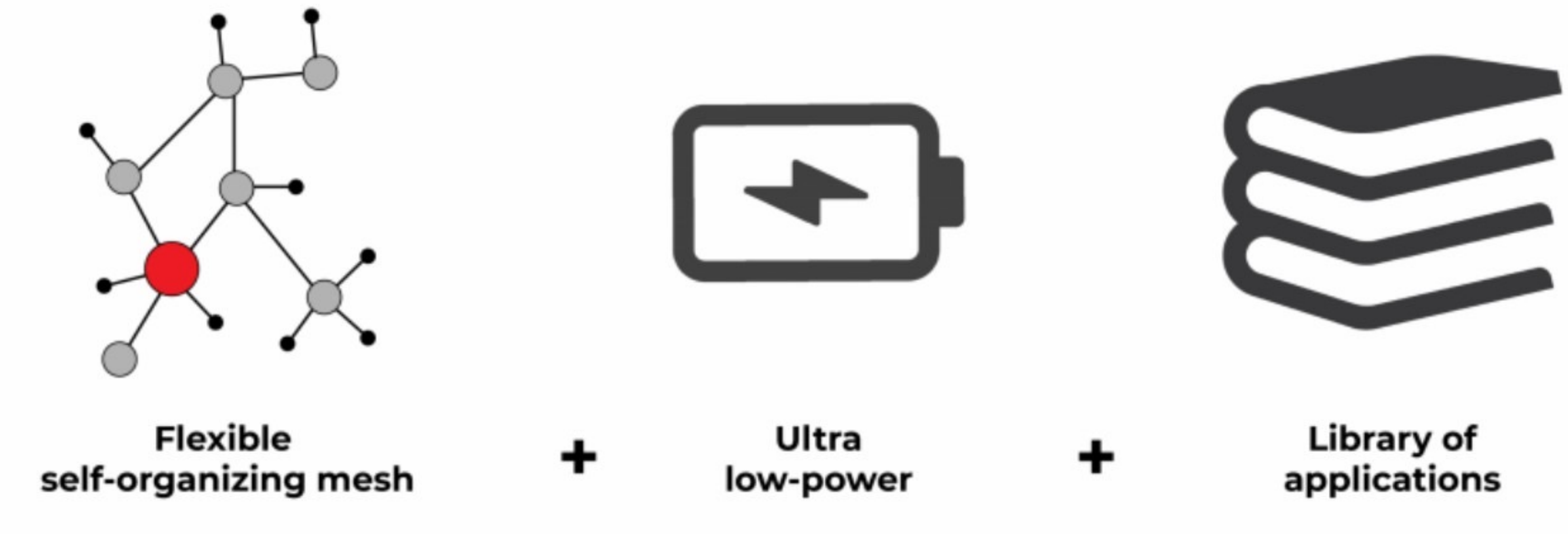
4. Zigbee

- **Zigbee** is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. Hence, Zigbee is a low-power, low data rate, and close proximity (i.e., personal area) wireless ad hoc network.

- Zigbee is a low-cost, low-power, wireless mesh network standard targeted at battery-powered devices in wireless control and monitoring applications. Zigbee delivers low-latency communication. Zigbee chips are typically integrated with radios and with microcontrollers. Zigbee operates in the industrial, scientific and medical (ISM) radio bands: 2.4 GHz in most jurisdictions worldwide; though some devices also use 784 MHz in China, 868 MHz in Europe and 915 MHz in the US and Australia, however even those regions and countries still use 2.4 GHz for most commercial Zigbee devices for home use. Data rates vary from 20 kbit/s (868 MHz band) to 250 kbit/s (2.4 GHz band).

https://en.wikipedia.org/wiki/Zigbee

zigbee (IEEE 802.15.4)



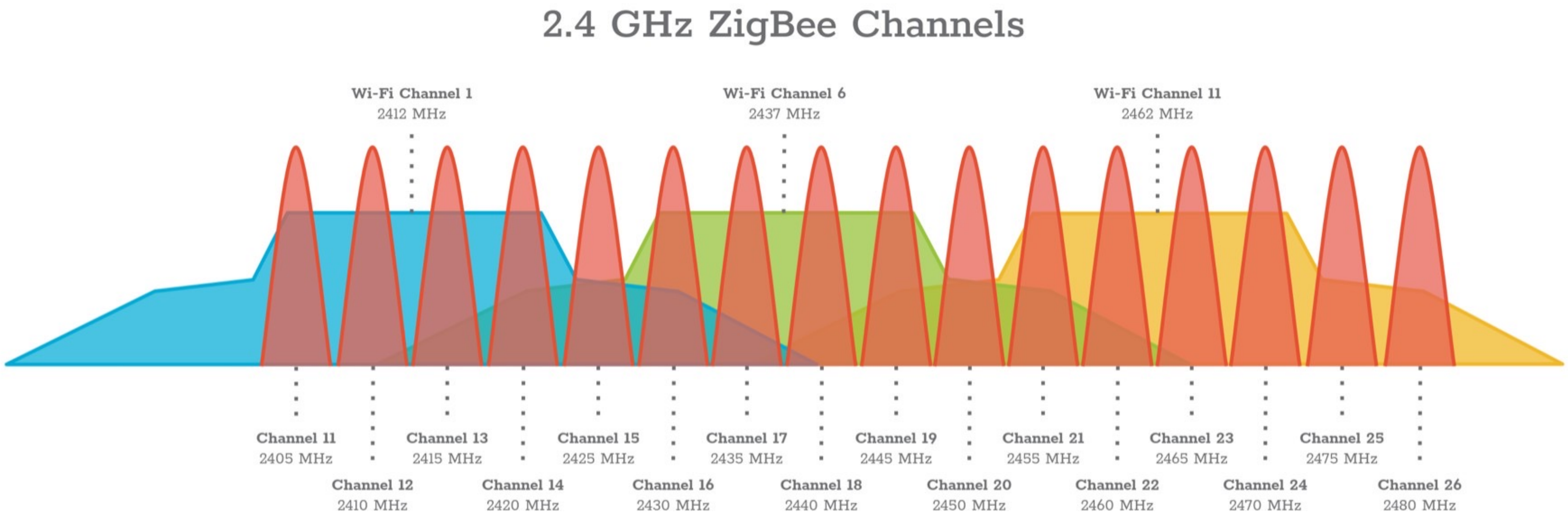
https://zigbeealliance.org/solution/zigbee/

ZigBee Radio Frequency (IEEE 802.15.4)

The ZigBee radio frequency is related to the WiFi frequency (2.4 GHz and 5 GHz). There are three frequency bands assigned to ZigBee but only one channel is used in a network

- Europe: Channel 0: 868.3 MHz
- US and Australia: Channel 1-10: 902 MHz – 928 MHz (2MHz each channel)
- Across the World: Channel 11-26: 2.4 GHz – 2.4835 GHz (5MHz each channel)

It is not recommended to use the exact WiFi frequency because this can cause in interference and usually the ZigBee network will take the hit. The following picture shows the WiFi and also the different ZigBee channels.



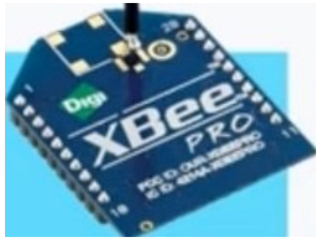
802.15.4 : LR-WPAN

- A technical standard which defines the operation of Low-Rate - Wireless Personal
Area Networks (LR-WPANs). Also provides compatible interconnection for data communicaton devices using low-data-rate, low-power, and low-complexity short-range radio frequency (RF) transmissions.

- Collection of standards for low-rate wireless personal area networks (LR **WPANs).**

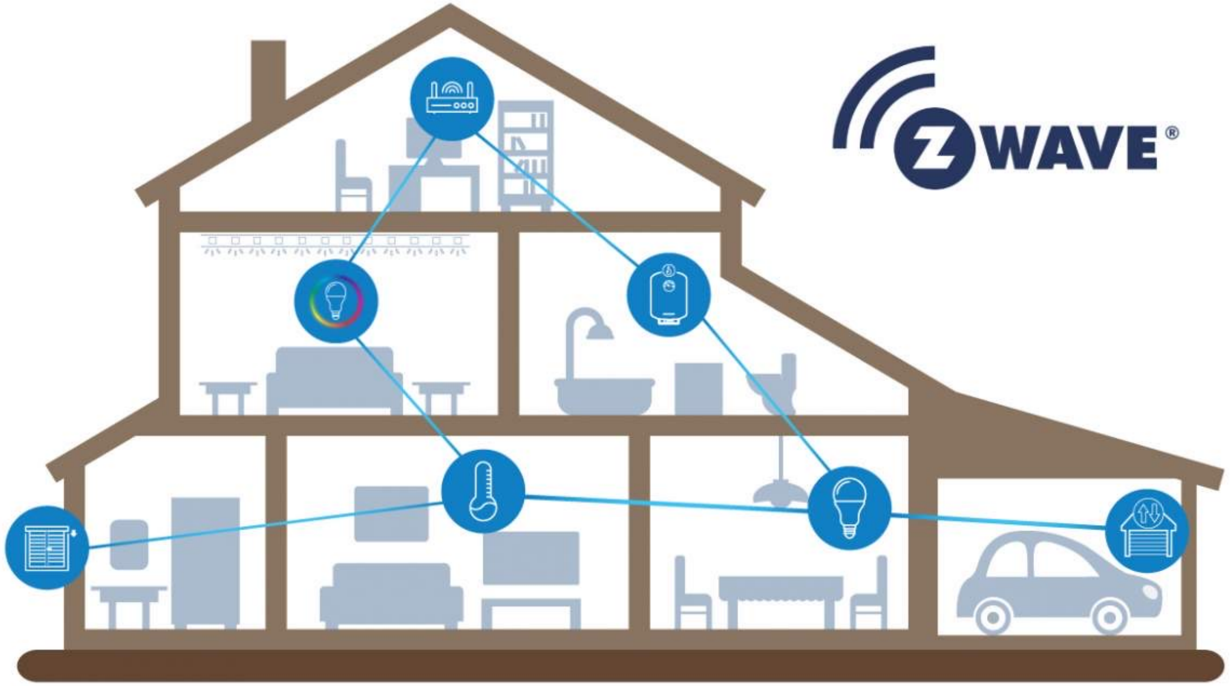
These standards form the basis of specifications for high level communication protocols such as ZigBee LR-WPAN standards provide data rates from 40 Kb/s 250 Kb/s.

These standards provide low-cost and low-speed communication for power constrained devices.



Z-Wave

A technology extensively applied in smart homes. Z-Wave devices can be attached to home appliances, which enable them to be controlled over the Internet.



www.z-wave.com

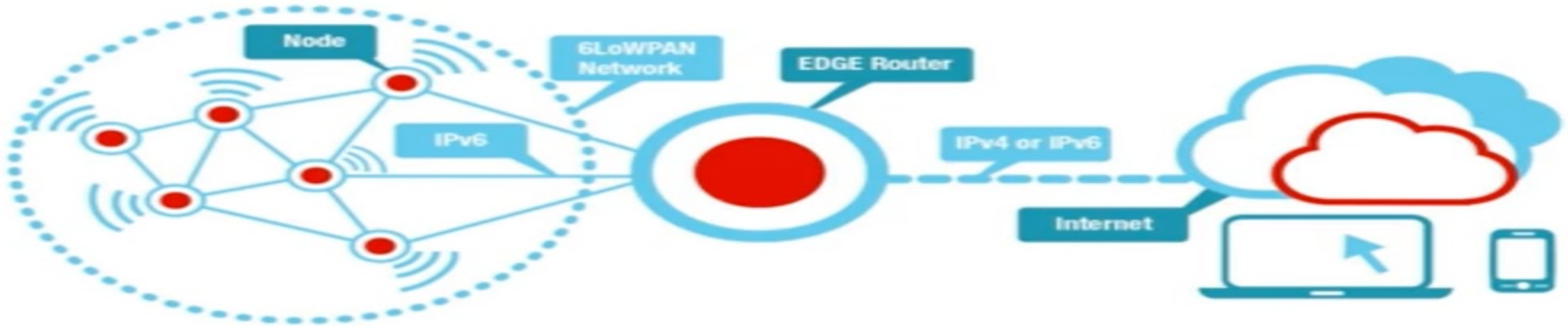
Z-Wave Vs. Zigbee: What do they have in common?

1. **Both technologies are mesh networks.** Each node in the system acts as both a wireless data source and a repeater. Information from a single sensor node hops from node to node until the transmission reaches the gateway. (We'll talk more later on whether this is the appropriate topology for your application.)
2. **Both technologies use the IEEE 802.15.4 low-rate personal area network (LR-PAN) protocol** for the unified physical layer (OSI layer 1), structuring packets, and creating MAC (Medium Access Control) schemes.
3. **Both are widely used in local area sensor data networks**, like in security systems, urban smart grid controllers, HVAC control systems, home automation, and lighting controls.

Z-Wave Vs. Zigbee: How are they different?

1. **Z-wave has a tightly controlled product ecosystem that caters to the smart home and smart building space, whereas Zigbee can be used for a number of applications.** There's no expectation that two Zigbee devices are interoperable unless the interoperability is preplanned. A Z-Wave application, on the other hand, will almost always integrate with another Z-Wave device. This is a major consideration for product engineers, which we'll discuss further in the section below.
2. **Zigbee uses the global standard 2.4GHz ISM frequency band, whereas Z-Wave uses the 915 MHz ISM band (in the U.S.) and the 868 MHz RFID band (in Europe).** Zigbee's global standard allows its hardware to be used in any country. However, the 2.4 GHz band can be subject to intense interference from WiFi and Bluetooth systems, whereas the sub-GHz bands Z-Wave uses do not face the same interference issues.
3. **Lots of providers make Zigbee radios, but Z-Wave uses a proprietary radio system from Sigma designs.** Since Z-Wave suffers from fewer interoperability problems than Zigbee, their proprietary radio system isn't necessarily a bad thing.
4. **Z-Wave uses frequency-shift keyed modulation (FSK), whereas Zigbee modulation is carried out through direct sequence spread spectrum (DSSS).** Each has its own pluses and minuses, and you can read more here on the difference between DSSS and FSK.

6LoWPAN



6LOWPAN:

- It is IPv6 over **L**ow **P**ower **W**ireless **P**ersonal **A**rea **N**etwork.
- Specially designed for devices which have **limited processing capability**.
- Operates in the 2.4 GHz frequency range and provides data transfer rates of 250 Kb/s.
- It works with the 802.15.4 link layer protocol, and defines compression mechanisms for IPv6 datagrams over IEEE 802.15.4 based networks.

5. Wi-Fi

Wi-Fi is particularly useful for ad hoc configurations, such as Wi-Fi Direct, which does not require a wireless access point.

The main limitation of Wi-Fi is its power consumption. However, in some IoT applications (e.g., smart homes), power is not an important issue.

The Wi-Fi Alliance is launching a new energy-efficient Wi-Fi technology named Wi-Fi HaLow[12] that is specifically designed for IoT nodes.

Wireless LAN Standards (WiFi)

Standards from the first years of WiFi:

IEEE Standard	Frequency Band	Data Rate	Modulation Technique	Multiplexing Technique
original 802.11	2.4 GHz	1 or 2 Mbps	FSK	DSSS
	2.4 GHz	1 or 2 Mbps	FSK	FHSS
	InfraRed	1 or 2 Mbps	PPM	– none –
802.11a	5.725 GHz	6 to 54 Mbps	PSK or QAM	OFDM
802.11b	2.4 GHz	5.5 and 11 Mbps	PSK	DSSS
802.11g	2.4 GHz	22 and 54 Mbps	various	OFDM

Wireless LAN Standards (WiFi) (cont'd)

More recent WiFi standards:

802.11n – Standardized in 2009.
-- Extends 802.11b and .11g
-- Uses the 2.4 GHz and 5 GHz frequency bands
-- Expected total multi-station throughput of 600 Mbps
-- Uses MIMO (Multiple Input Multiple Output) by having multiple antennae at both sender and receiver
-- Up to 4 more MIMO spatial streams

Standard	Purpose
802.11e	Improved quality of service, such as a guarantee of low jitter
802.11h	Like 802.11a, but adds control of spectrum and power (primarily intended for use in Europe)
802.11i	Enhanced security, including Advanced Encryption Standard; the full version is known as WPA2
802.11k	Will provide radio resource management, including transmission power
802.11n	Data rate over 100 Mbps to handle multimedia (video) applications (may be 500 Mbps)
802.11p	Dedicated Short-Range Communication (DSRC) among vehicles on a highway and vehicle-to-roadside
802.11r	Improved ability to roam among access points without losing connectivity
802.11s	Proposed for a mesh network in which a set of nodes automatically form a network and pass packets

802.11ac – Preliminary versions now showing up in new WiFi Routers.
-- WLANs on the 5 GHz frequency bands
-- Final standard approval expected in early 2014
-- Expected total multi-station throughput of 1 Gbps; single link throughput 500 Mbps
-- Extends 802.11n capabilities with: wider RF band & up to 8 MIMO spatial streams

802.11 a/b/g/n Explained

802.11 Protocol	Frequency	Modulation	Bandwidth	Data Rates (Mb/s)	# MIMO Streams	Comments
a	5 GHz	OFDM	20 MHz	6, 9, 12, 18, 24, 36, 48, 54	1	High frequency reduces effective range.
b	2.4 GHz	DSSS	20 MHz	1, 2, 5.5, 11	1	Many IT departments are turning off "b" access points.
g	2.4 GHz	OFDM & DSSS	20 MHz	6, 9, 12, 18, 24, 36, 48, 54	1	Only *universal* module scheme. Access points auto-adjust rate to minimize the packet error rate.
n	2.4 GHz & 5 GHz	OFDM	20 MHz & 40 MHz	7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2 (per stream)	4	Must implement MIMO and 40 MHz bandwidth to get maximum data rates (600 Mb/s).

802.11 uses latency and rate reduction as a means of addressing increasing packet error rates and increasing range. Thus, the ability to step down through rates is part of the specification to create robust, high range networks.

802.11*a* is used to isolate networks and avoid crowded 2.4 GHz spectrums.

- For example – hospitals and patient records

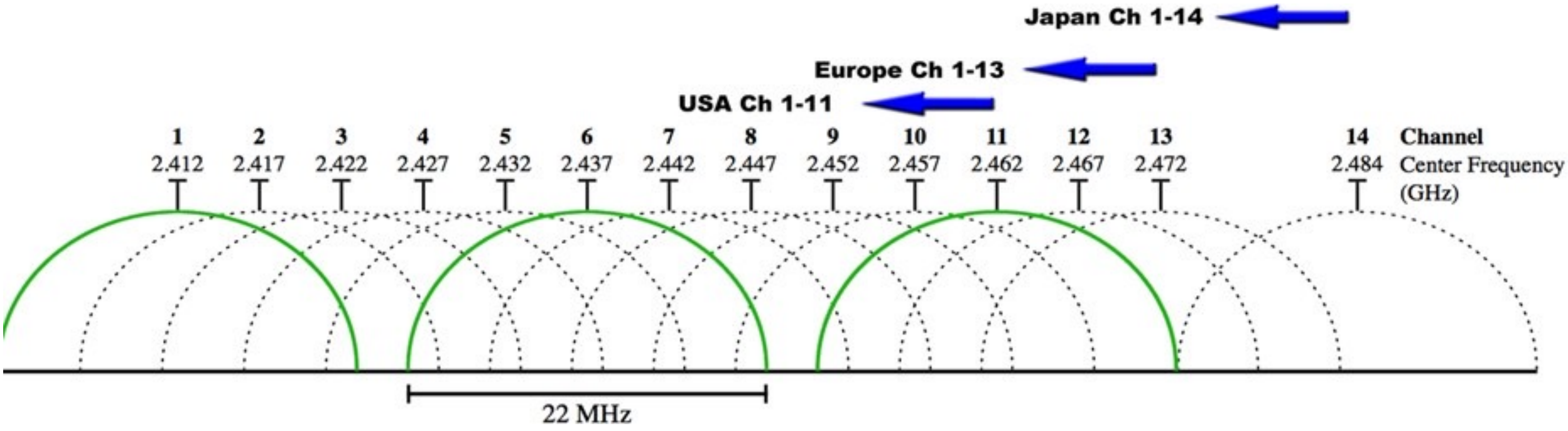
802.11*g* is an energy efficient radio that is fully compatible with basic 802.11n networks.

- Same modulation technique

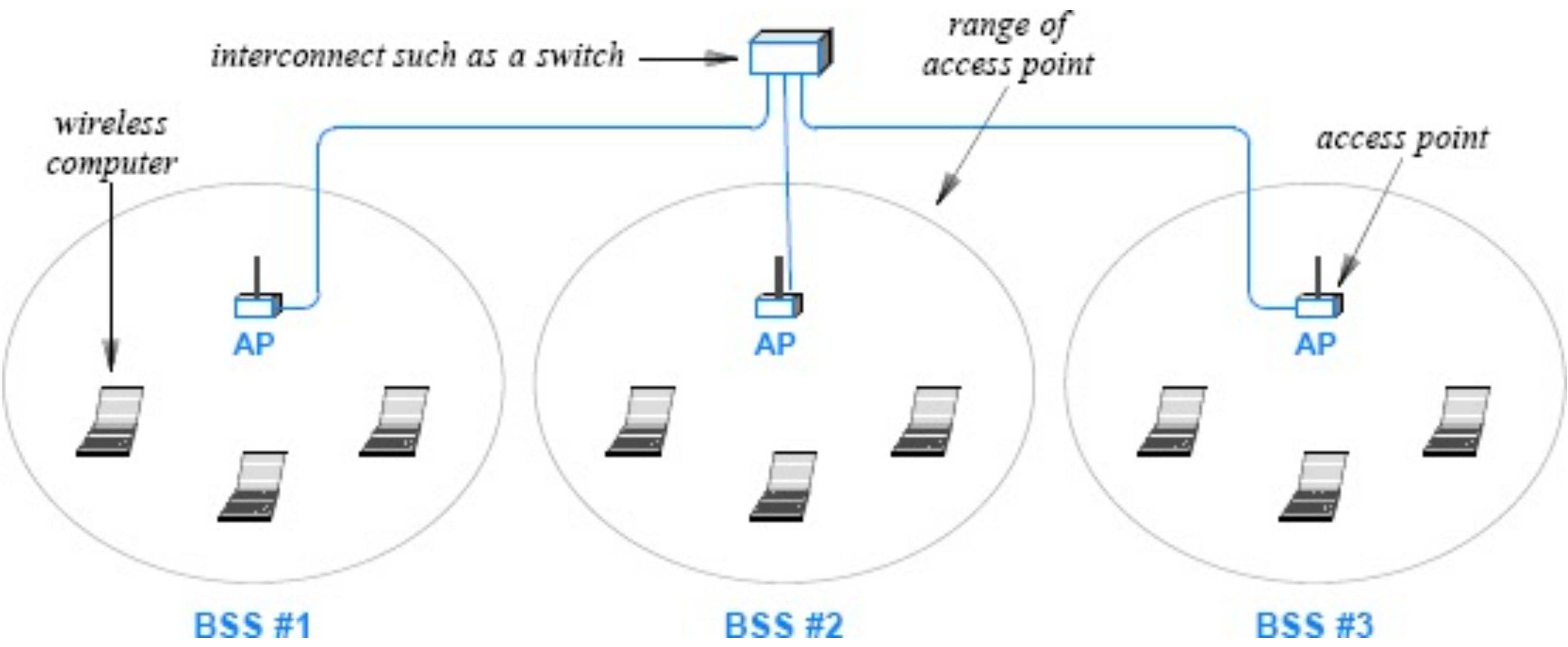
802.11*n* is useful for high data throughput applications.

- High definition video, moving Mbytes of data
- Must implement bonding and Multiple Input Multiple Output (MIMO) to achieve higher rates

802.11 operates over two major spectral bands: the ISM band covering **2.4 GHz - 2.485 GHz spectrum** and the 5 GHz band. **The ISM band is divided into** 14 channels at different frequencies. The center frequencies are separated by 5 MHz (i.e. 2412, 2417, 2422, etc). However, the bandwidth is +/- 10 MHz. Hence, there is a significant spectral overlap on adjacent channels (i.e choosing an adjacent channel to another network is almost as bad as choosing the same channel).



Wireless Local Area Network (WLAN) Architecture



Note: The set of computers within range of a given access point is known as a ***Basic Service Set (BSS).***

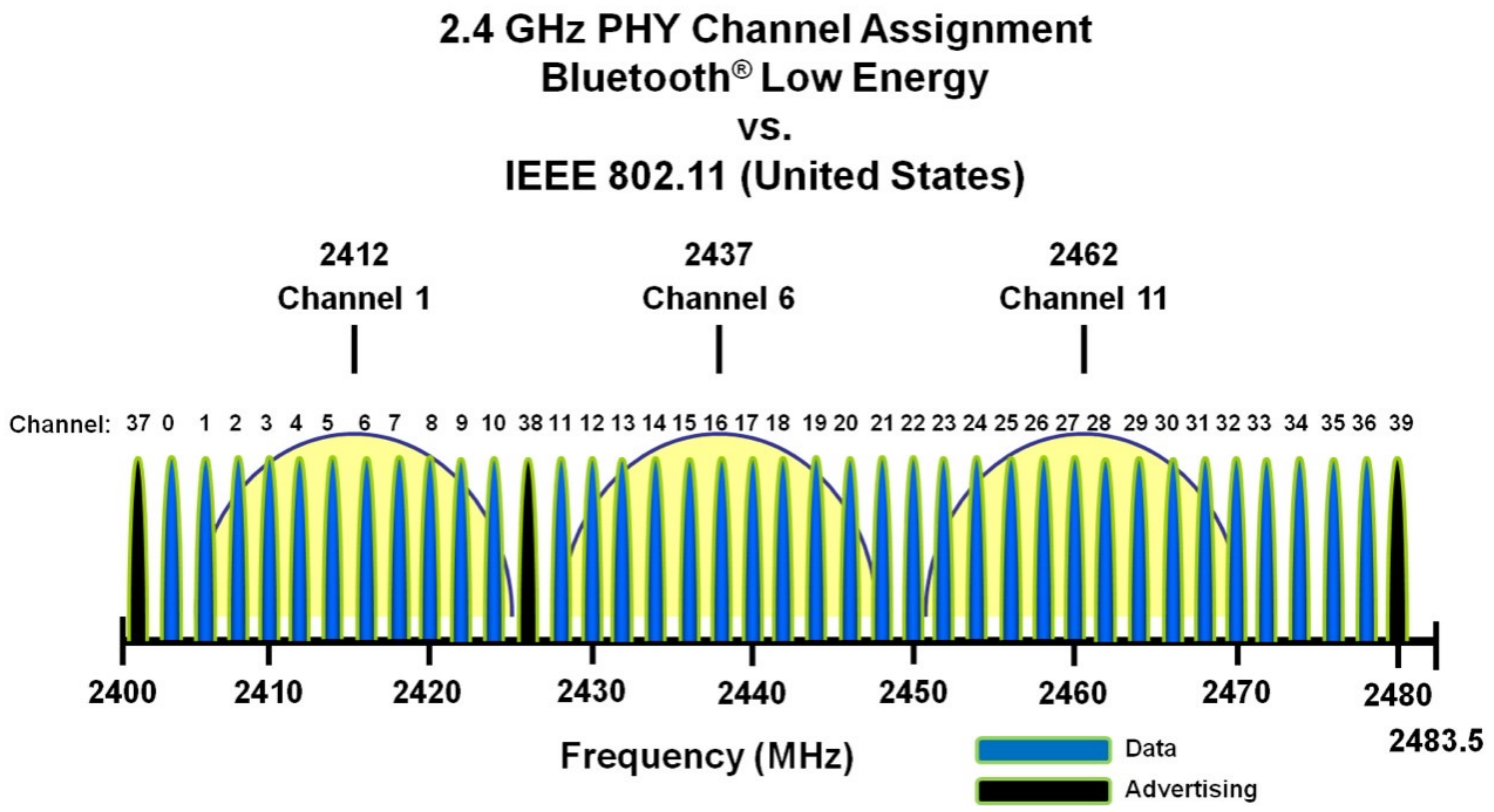
Comparison chart

	Bluetooth	Wi-Fi
Frequency	2.4 GHz	2.4, 3.6, 5 GHz
Cost	Low	High
Bandwidth	Low (800 Kbps)	High (11 Mbps)
Specifications authority	Bluetooth SIG	IEEE, WECA
Security	It is less secure	Security issues are already being debated.
Year of development	1994	1991
Primary Devices	Mobile phones, mouse, keyboards, office and industrial automation devices. Activity trackers, such as Fitbit and Jawbone.	Notebook computers, desktop computers, servers, TV, Latest mobiles.

	Bluetooth	Wi-Fi
Hardware requirement	Bluetooth adaptor on all the devices connecting with each other	Wireless adaptors on all the devices of the network, a wireless router and/or wireless access points
Range	5-30 meters	With 802.11b/g the typical range is 32 meters indoors and 95 meters (300 ft) outdoors. 802.11n has greater range. 2.5GHz Wi-Fi communication has greater range than 5GHz. Antennas can also increase range.
Power Consumption	Low	High
Ease of Use	Fairly simple to use. Can be used to connect upto seven devices at a time. It is easy to switch between devices or find and connect to any device.	It is more complex and requires configuration of hardware and software.
Latency	200ms	150ms
Bit-rate	2.1Mbps	600 Mbps

Co-existence with 802.11/Wi-Fi®

Since the advertising channels form the basis for how BLE operates, they have been assigned center frequencies that minimize overlapping with the most common 802.11 channels, as shown:



Wireless MAN Technology and WiMAX

Standardized by IEEE under the category **IEEE 802.16**.

Two main versions of WiMAX are being developed that differ in their overall approach:

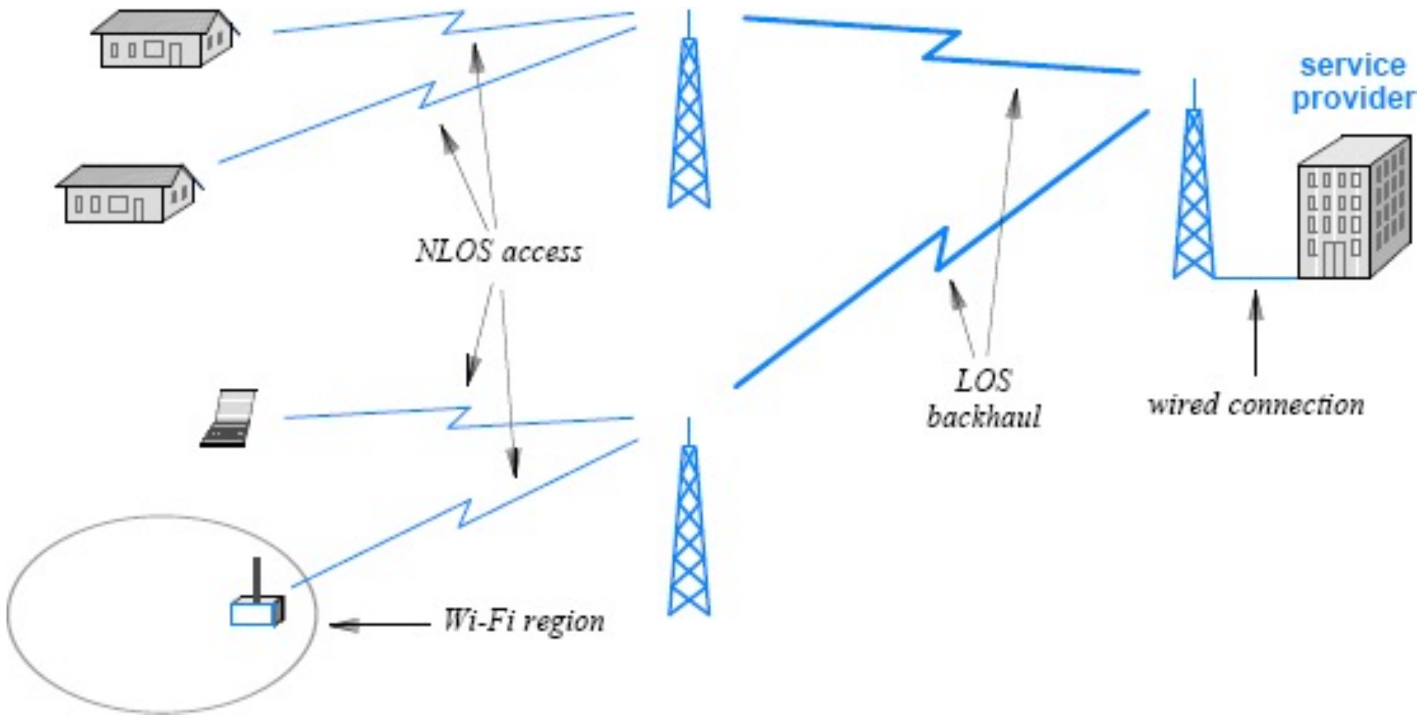
Fixed WiMAX

- refers to systems built using IEEE 802.16-2004 (informally called 802.16d)
- does not provide for handoff among access points
- provides connections between a service provider and a fixed location

Mobile WiMAX

- Standard 802.16e-2005 (informally called 802.16e)
- handoffs among Aps
- used for mobile hosts

Wireless MAN Technology and WiMAX (cont'd)



The key features of WiMAX can be summarized as follows:

- Uses licensed spectrum (i.e., offered by carriers)
- Each cell can cover a radius of 3 to 10 Km
- Uses scalable orthogonal FDM
- Guarantees quality of services (for voice or video)
- Can transport 70 Mbps in each direction at short distances
- Provides 10 Mbps over a long distance (10 Km)

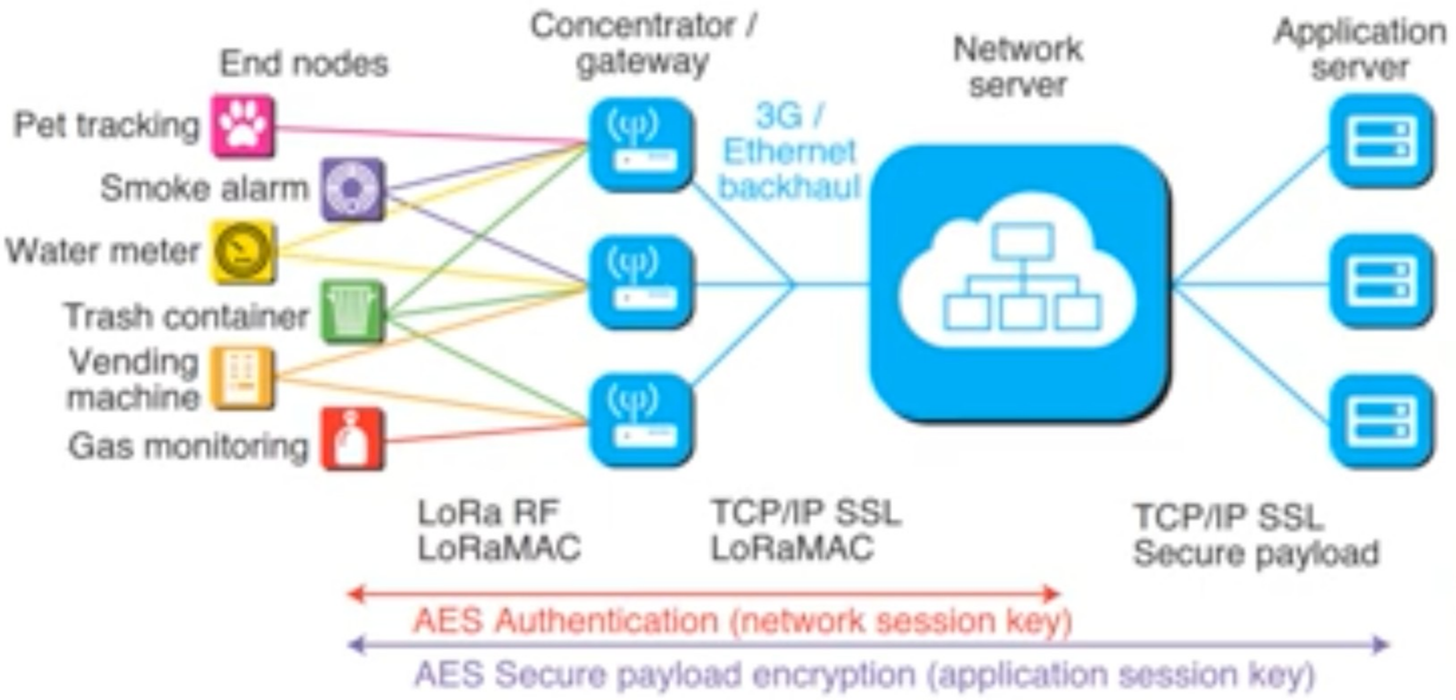
7 . Long-Range Wide-Area Network (LoRaWAN)

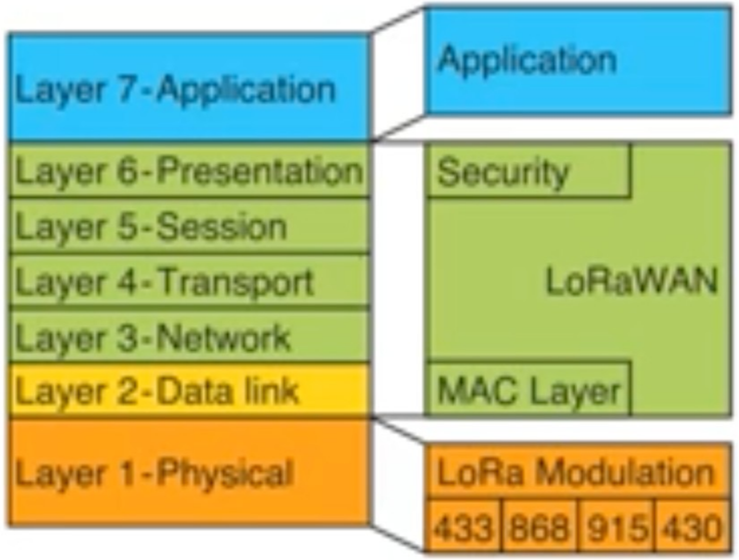
- A technology from LoRa Alliance that offers low-cost, mobile, and secure bidirectional communication.

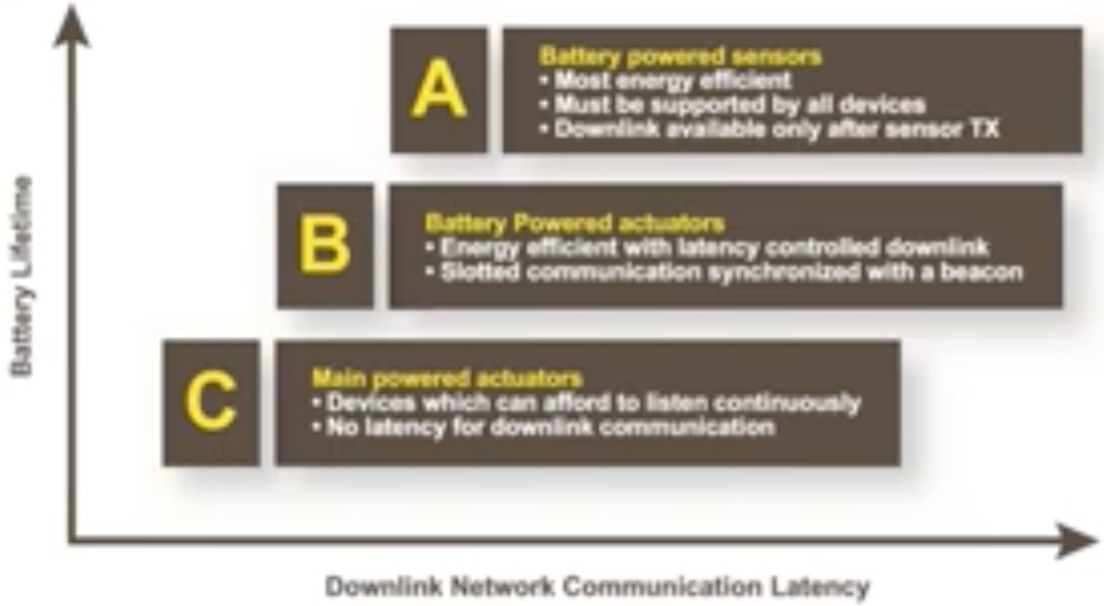
- It is optimized for low power consumption and is designed to support large networks with millions of nodes, which renders it ideal for IoT applications such as smart cities and industrial applications.

www.lora-alliance.org/For-Developers/LoRaWANDevelopers

LoRa (Long Range)/LoRaWAN



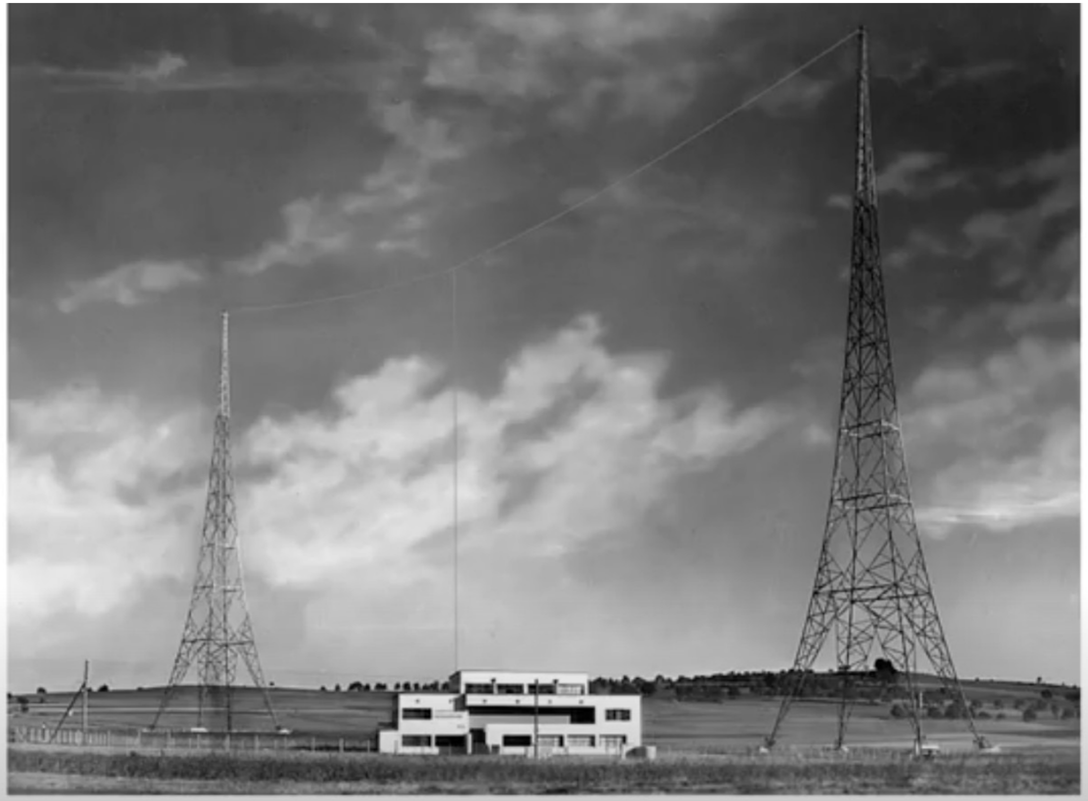




WHAT IS LoRa®?

LoRa® is the physical layer or the wireless modulation utilized to create the long range communication link. Many legacy wireless systems use frequency shifting keying (FSK) modulation as the physical layer because it is a very efficient modulation for achieving low power. LoRa® is based on chirp spread spectrum modulation, which maintains the same low power characteristics as FSK modulation but significantly increases the communication range. **Chirp spread spectrum** has been used in military and space communication for decades due to the long communication distances that can be achieved and robustness to interference, but LoRa® is the first low cost implementation for commercial usage.

https://lora-alliance.org



Bandwidth

Wide Area ⟷ Low Power

One technology cannot serve all of the projected applications and volumes for IoT. WiFi and BTLE are widely adopted standards and serve the applications related to communicating personal devices quite well. Cellular technology is a great fit for applications that need high data throughput and have a power source. LPWAN offers multi-year battery lifetime and is designed for sensors and applications that need to send small amounts of data over long distances a few times per hour from varying environments

	Local Area Network Short Range Communication	**Low Power Wide Area** (LPWAN) Internet of Things	**Cellular Network** Traditional M2M
	40%	**45%**	**15%**
	Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
	Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
	Bluetooth 4.0 WiFi	LoRa	GSM 3G+ / H+ 4G

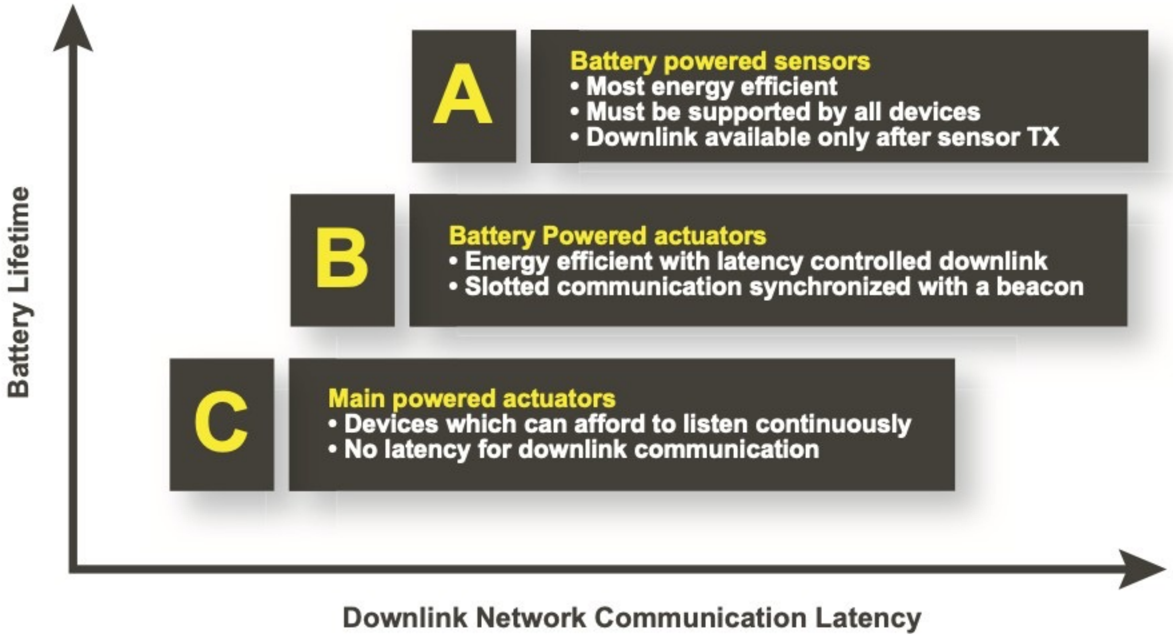
IMPORTANT FACTORS IN LPWAN

The most critical factors in a LPWAN are:

- Network architecture
- Communication range
- Battery lifetime or low power
- Robustness to interference
- Network capacity (maximum number of nodes in a network)
- Network security
- One-way vs two-way communication
- Variety of applications served

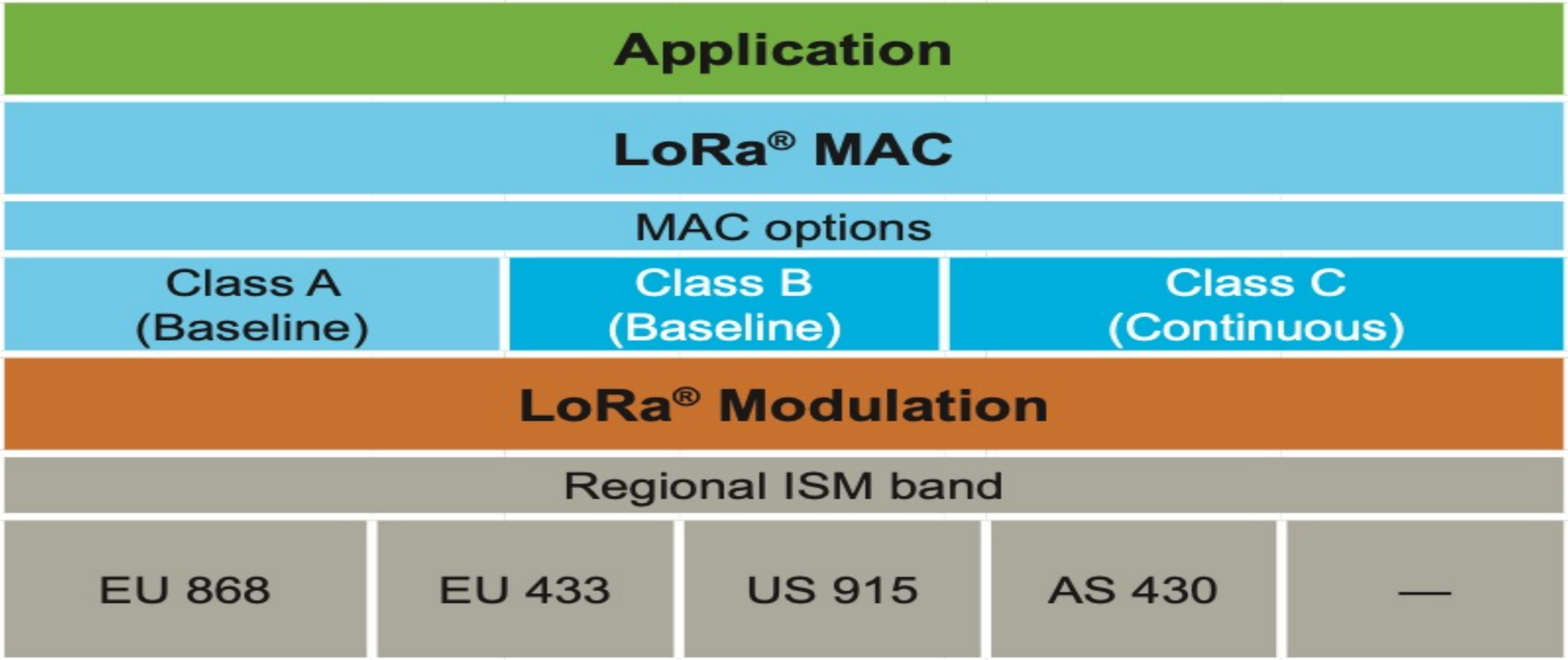
Device Classes – Not All Nodes Are Created Equal

End-devices serve different applications and have different requirements. In order to optimize a variety of end application profiles, LoRaWAN™ utilizes different device classes. The device classes trade off network downlink communication latency versus battery lifetime. In a control or actuator-type application, the downlink communication latency is an important factor.



WHAT IS LoRaWAN™?

LoRaWAN™ defines the communication protocol and system architecture for the network while the LoRa® physical layer enables the long-range communication link. The protocol and network architecture have the most influence in determining the battery lifetime of a node, the network capacity, the quality of service, the security, and the variety of applications served by the network.



LoRa or LoRaWAN

The term LoRa and LoRaWAN are often used in a mixed fashion but by definition there is a difference. LoRa defines the standard for the physical (layer 1) standard, LoRaWAN defines all that plus the MAC layer and application standards.

LoRaWAN is a wireless communication standard. You could put it in the same category of Bluetooth, GSM, 3G, LTE,… but it’s still different.

It has the range of your mobile phone with the flexibility of Bluetooth or WiFi and the battery life of your watch for minimum cost.

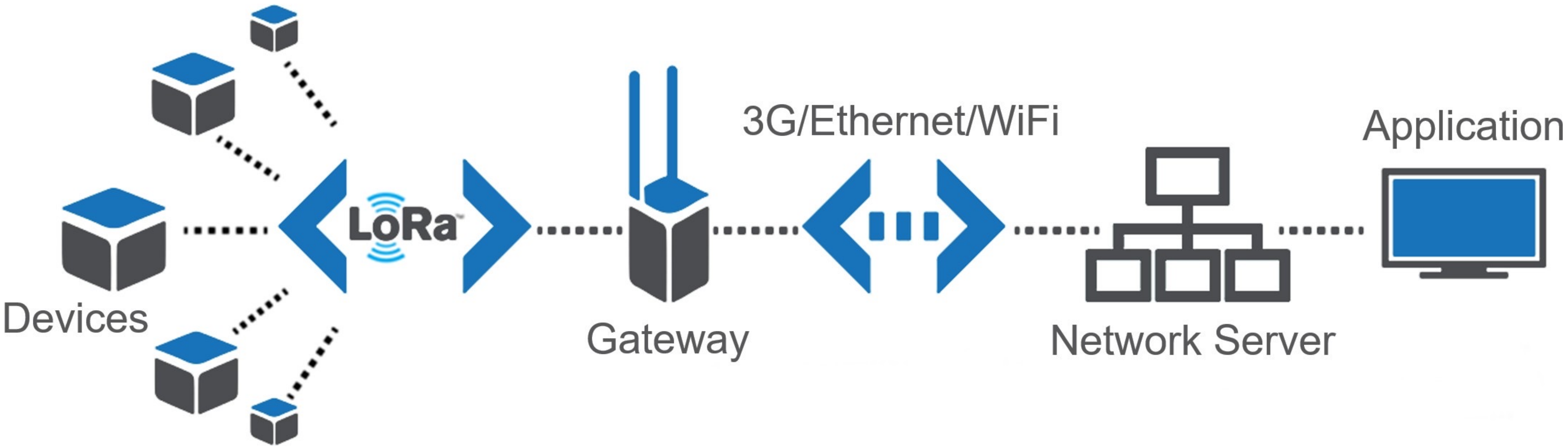
The main characteristics of LoRaWAN are:

- Long range (>5 km urban, >10 km suburban, >80 km VLOS)
- Long battery life (>10 years)
- Low cost (<$5/module)
- Low data rate (0.3 bps – 50 kbps, typically ~ 10 kB/day)
- Secure + Operates in unlicensed spectrum
- Localization support
- Bidirectional

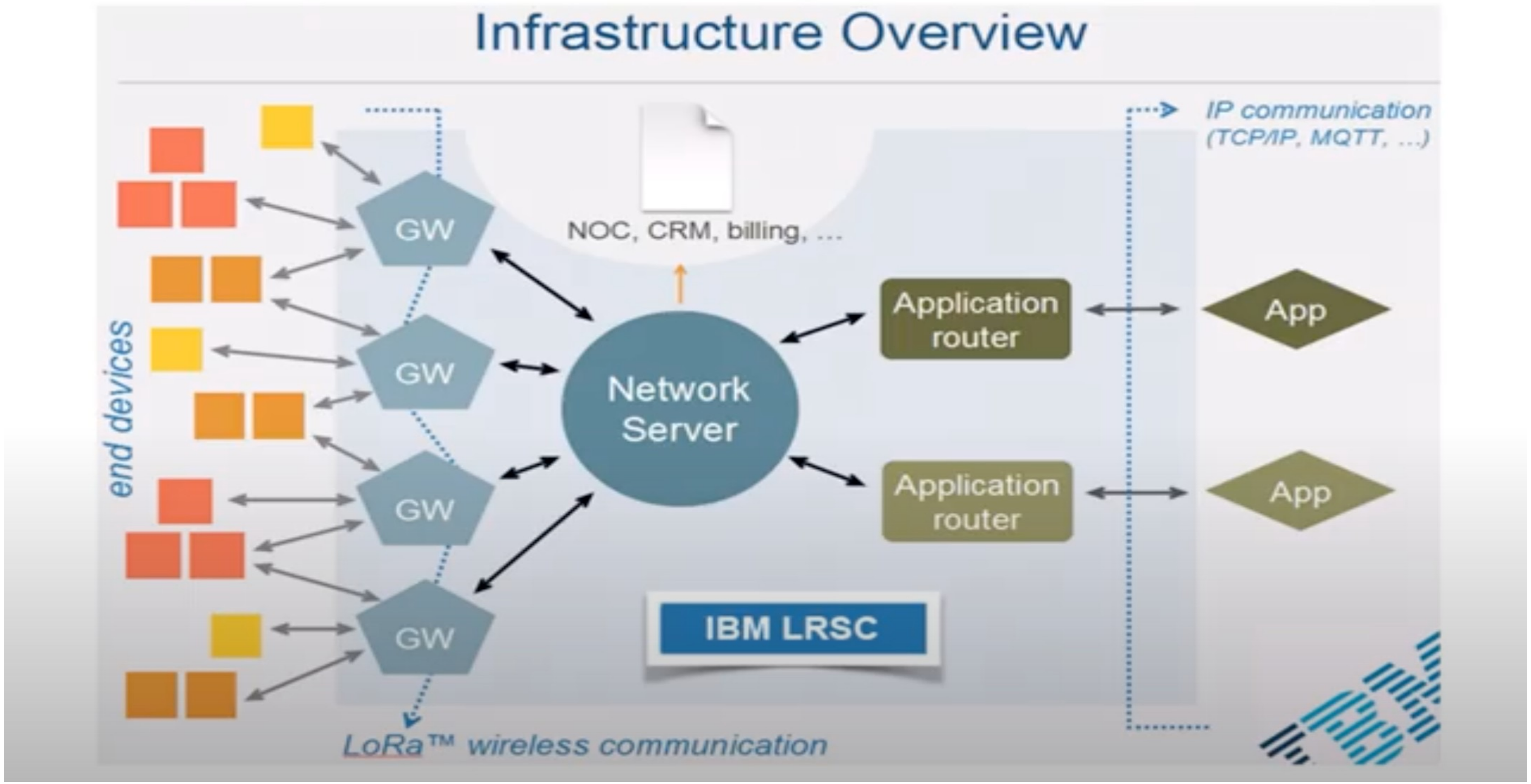
Architecture

For upstream messages, for example a sensor that sends information to an application, the flow is from left to right. The sensor value (payload) gets encrypted and gets transmitted over LoRa radio. One or more gateways receive the message and forward it over another network (typically 3G or Ethernet) to a Network Server. The Network Server routes the message to the correct end application.

For downstream messages, for example a signal to turn on a light, the flow is from right to left. Upstream messages are initiated by the device itself and downstream by the end application. Since LoRa is designed with as low energy usage as possible, not all devices are always listening for incoming messages. This depends on the device classes



LoRaWAN



Practical Lora: https://www.youtube.com/watch?v=7n8t62anxIQ

WHAT IS LoRaWAN™?

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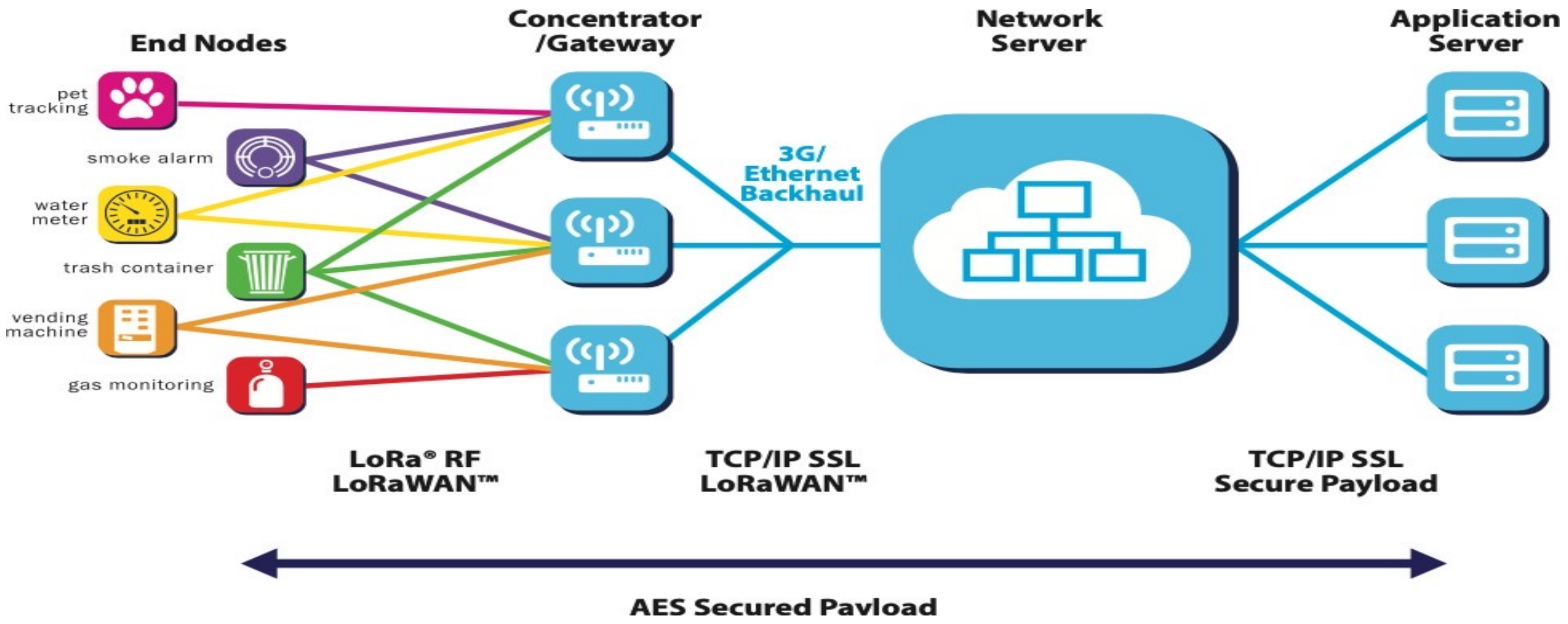
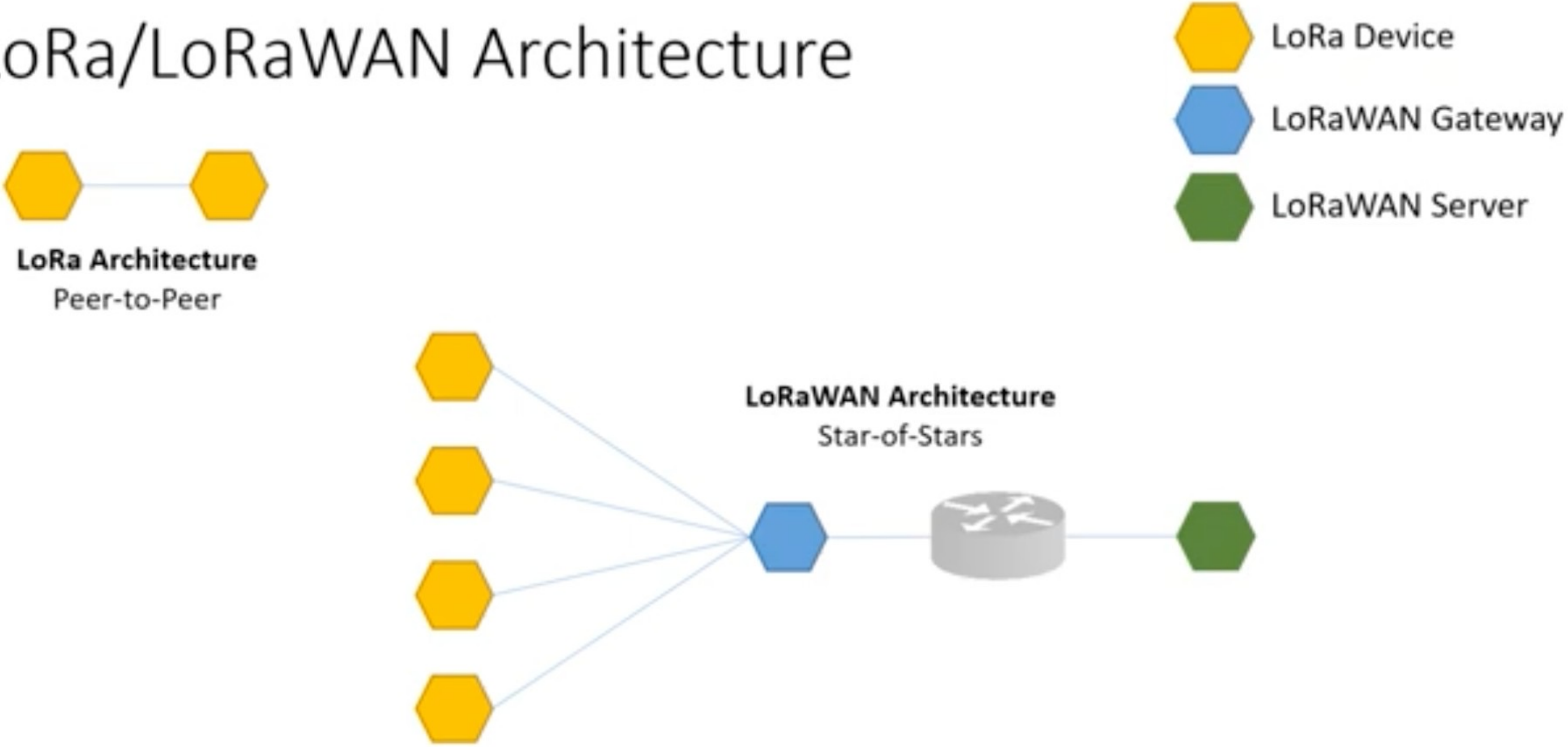


LoRa/LoRaWAN Architecture

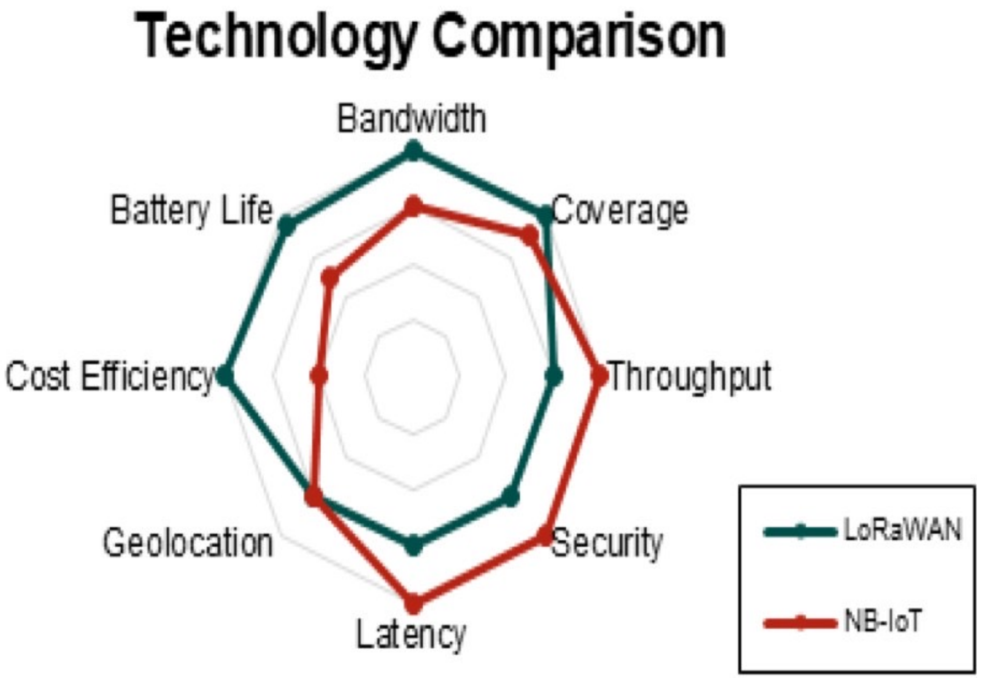


NarrowBand-Internet of Things (NB-IoT) is a standards-based low power wide area (LPWA) technology developed to enable a wide range of new IoT devices and services. NB-IoT significantly improves the power consumption of user devices, system capacity and spectrum efficiency, especially in deep coverage. Battery life of more than 10 years can be supported for a wide range of use cases.

New physical layer signals and channels are designed to meet the demanding requirement of extended coverage – rural and deep indoors – and ultra-low device complexity. Initial cost of the NB-IoT modules is expected to be comparable to GSM/GPRS. The underlying technology is however much simpler than today's GSM/GPRS and its cost is expected to decrease rapidly as demand increases.

Technology Parameters	LoRaWAN	NB-IoT
Bandwidth	125 kHz	180 kHz
Coverage	165 dB	164 dB
Battery Life	15+ years	10+ years
Peak Current	32 mA	120 mA
Sleep Current	1μA	5μA
Throughput	50 Kbps	60 Kbps
Latency	Device Class Dependent	< 10 s
Security	AES 128 bit	3GPP (128 to 256 bit)
Geolocation	Yes (TDOA)	Yes (in 3GPP Rel 14)
Cost Efficiency (Device and Network)	High	Medium

Source: ABI Research



https://lora-alliance.org/sites/default/files/2019-06/cr-lora-102_lorawanr_and_nb-iot.pdf

What Is SigFox?

Specifically, SigFox sets up antennas on towers (like a cell phone company), and receives data transmissions from devices like parking sensors or water meters. These transmissions use frequencies that are unlicensed, which in the US is the 915 MHz ISM band; the same frequency a cordless phone uses. (Europe has a narrower band around 868 MHz, and most of the world has some version of this band either like the US or Europe, all with different rules that govern their use.)

SigFox wireless systems send very small amounts of data (12 bytes) very slowly (300 baud) using standard radio transmission methods (phase-shift keying - DBPSK - going up and frequency-shift keying - GFSK - coming down). The long range is accomplished as a result of very long and very slow messages. **Information theory** says that the slower you transmit, the easier it is to "hear" your message.

This technology is a good fit for any application that needs to send small, infrequent bursts of data. Things like basic alarm systems, location monitoring, and simple metering are all examples of one-way systems that might make sense for this network. In these networks, the signal is typically sent a few times to "ensure" the message goes through. While this works, there are some limitations, such as shorter battery life for battery-powered applications, and an inability to guarantee a message is actually received by the tower.

An Overview of Enabling Technologies for the Internet of Things

Part II

8. Cellular mobile phone networks basics

The Beginning

Dyna-Tac

New Take-Along Telephones Give You Pushbutton Calling to Any Number

This amazing phone system could handle thousands of calls simultaneously, patching yours directly into a phone exchange

By JOHN R. FREE

Handsets Evolution (from the brick to the slick)

1983: Motorola DynaTAC 8000X

Analog voice

World's first handheld cellular phone call in public

On April 3, 1973, Motorola installed a base station to handle the first public demonstration of a phone call over the cellular network

weighed about 2.5 lb (1.1 kg).

Cooper and Motorola took the cellular phone technology to **New York** to demonstrate it to reporters and the public, standing on **Sixth Avenue** in New York City near the New York Hilton hotel, Cooper made a phone call from a prototype **Dyna-Tac** handheld cellular phone before going to a press conference upstairs in the

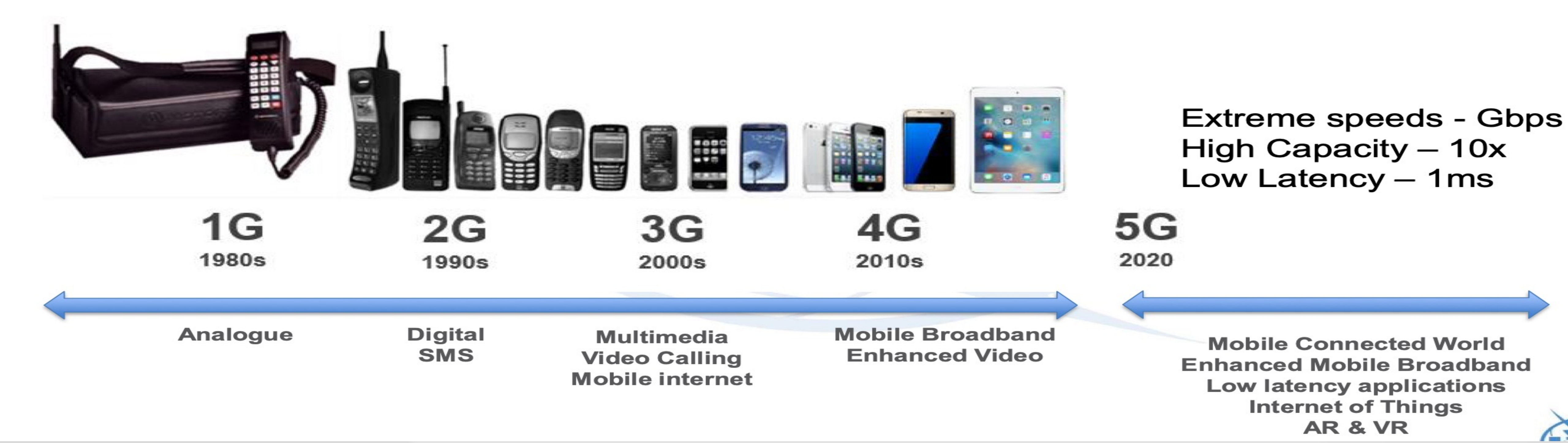
Mobile phone systems Evolution (the road to 4Gand What is LTE?)

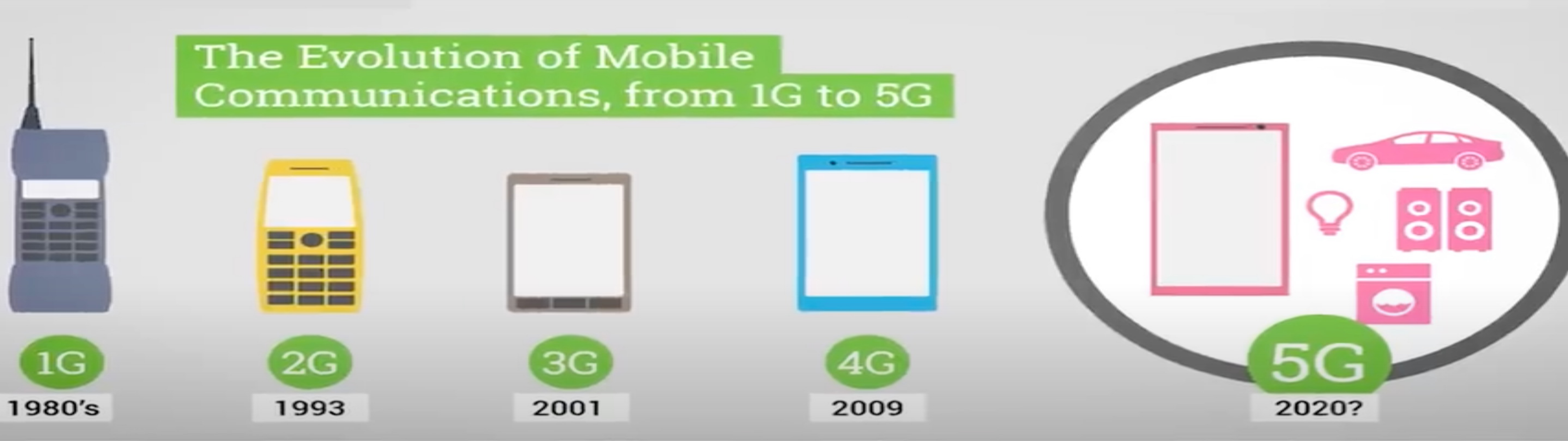
2012: The year LTE becomes a standard, not a luxury

4G LTE. The fastest cellular network.

What is LTE?

Wifi+ 4G


Extreme speeds - Gbps
High Capacity – 10x
Low Latency – 1ms
1G
1980s
2G
1990s
3G
2000s
4G
2010s
5G
2020
Analogue
Digital
SMS
Multimedia
Video Calling
Mobile internet
Mobile Broadband
Enhanced Video
Mobile Connected World
Enhanced Mobile Broadband
Low latency applications
Internet of Things
AR & VR

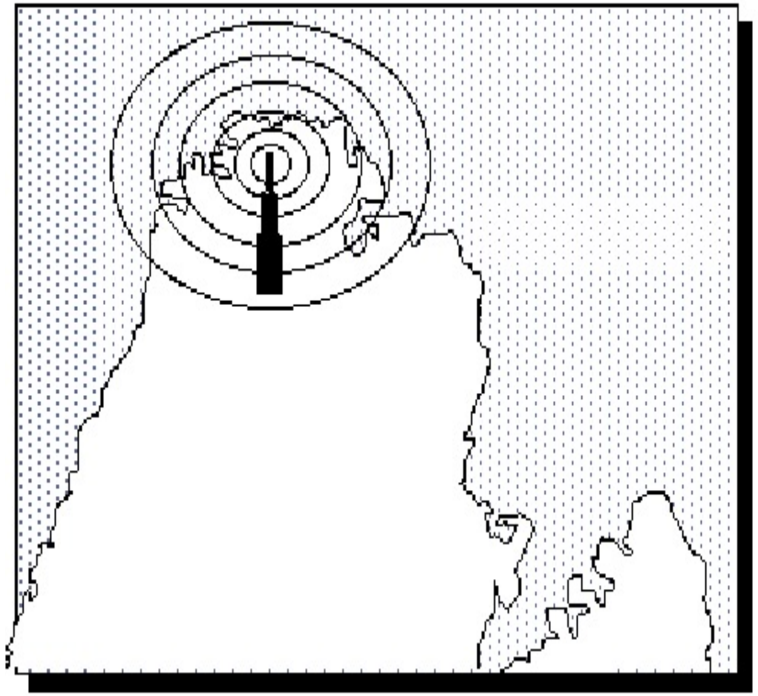

The Evolution of Mobile
Communications, from 1G to 5G
1G
1980's
2G
1993
3G
2001
4G
2009
5G
2020?

Cellular Network Fundamentals

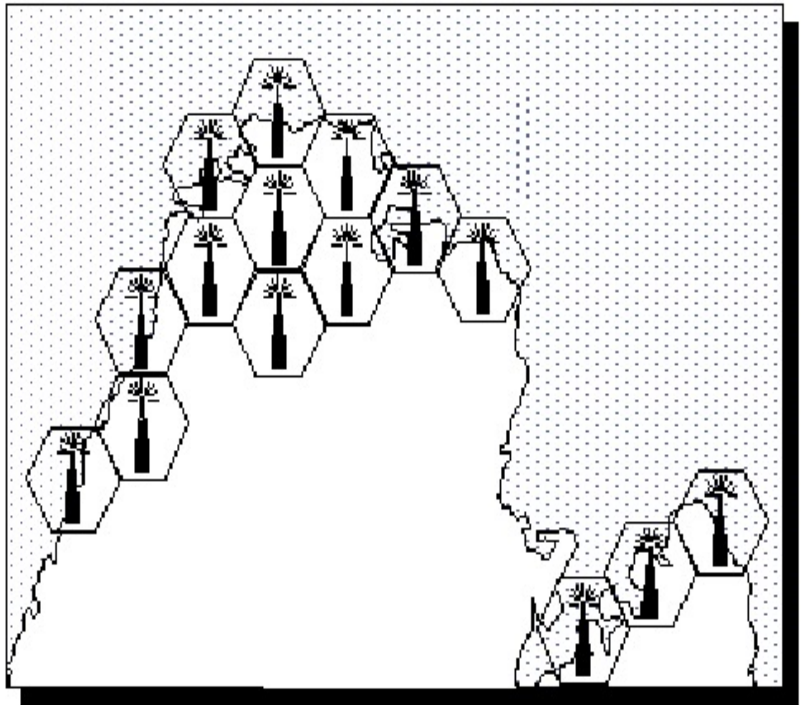
Rank	Country or region	Number of mobile phones	Population	% of population	Last updated date
	World	Over 6.6 billion	7,012,000,000[1]	79.86	2011[2]
1	China	1,010,000,000	1,341,000,000[3]	75.32	March 2012[4][5][6]
2	India	919,170,000	1,210,193,422[7]	76.00	Mar 2012 [8]
3	United States	327,577,529	310,866,000[9]	103.9	June 2011[10]
4	Brazil	250,800,000	192,379,287 [11]	130.36	April 2012[12]
5	Indonesia	250,100,000	237,556,363	105.28	May 2009[13]
6	Russia	224,260,000	142,905,200[14]	154.5	July 2011[15]
7	Japan	121,246,700	127,628,095	95.1	June 2011[16]
8	Pakistan	114,610,000	178,854,781[17]	66.5	Jan 2012[18] [19]
9	Germany	107,000,000	81,882,342	130.1	2009[20]
10	Nigeria	90,583,306	140,000,000	64.7	Feb. 2011[21]

Cellular Telephone Systems

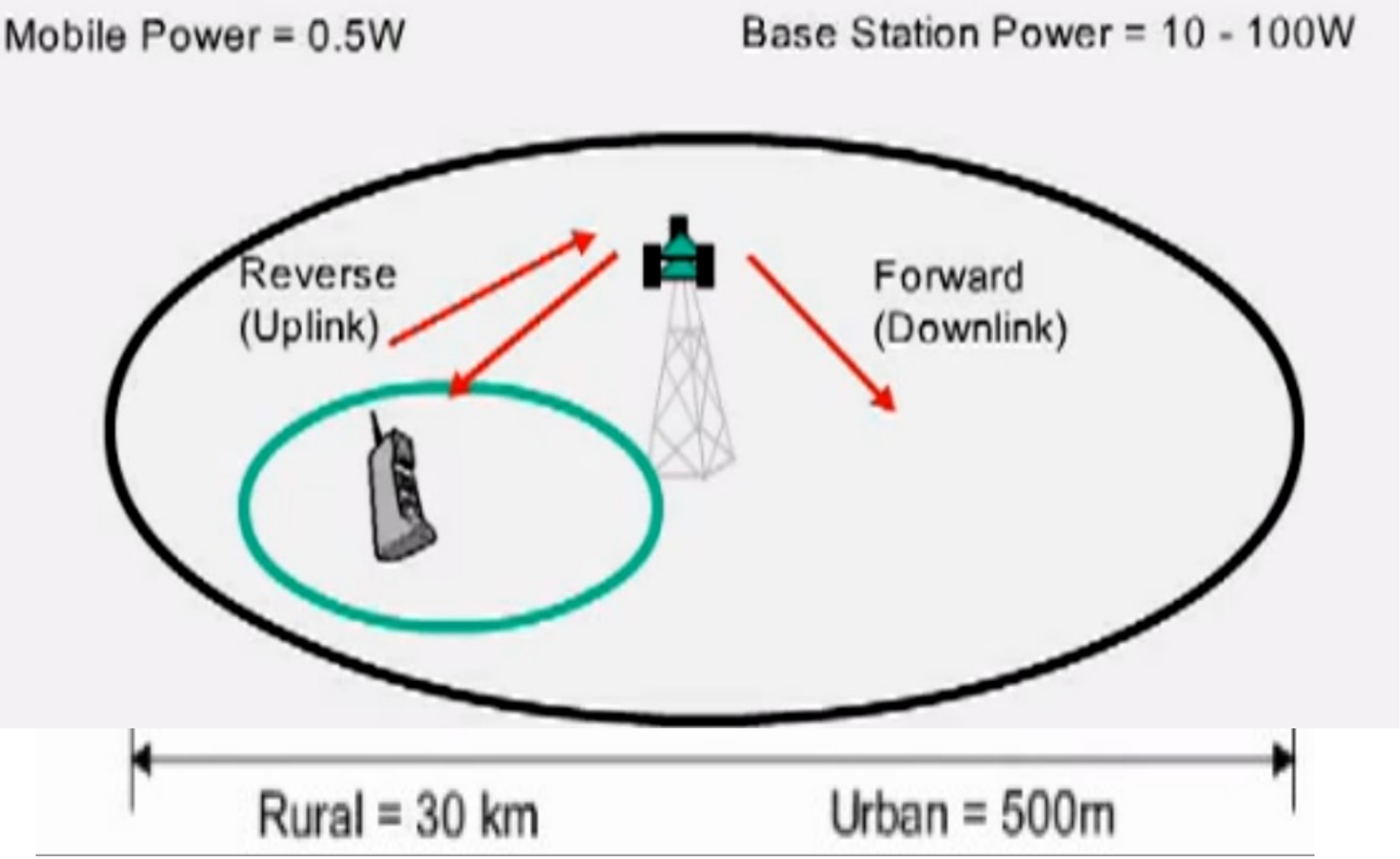
Early Mobile Telephone System Architecture



Mobile Telephone System Using Cellular Architecture

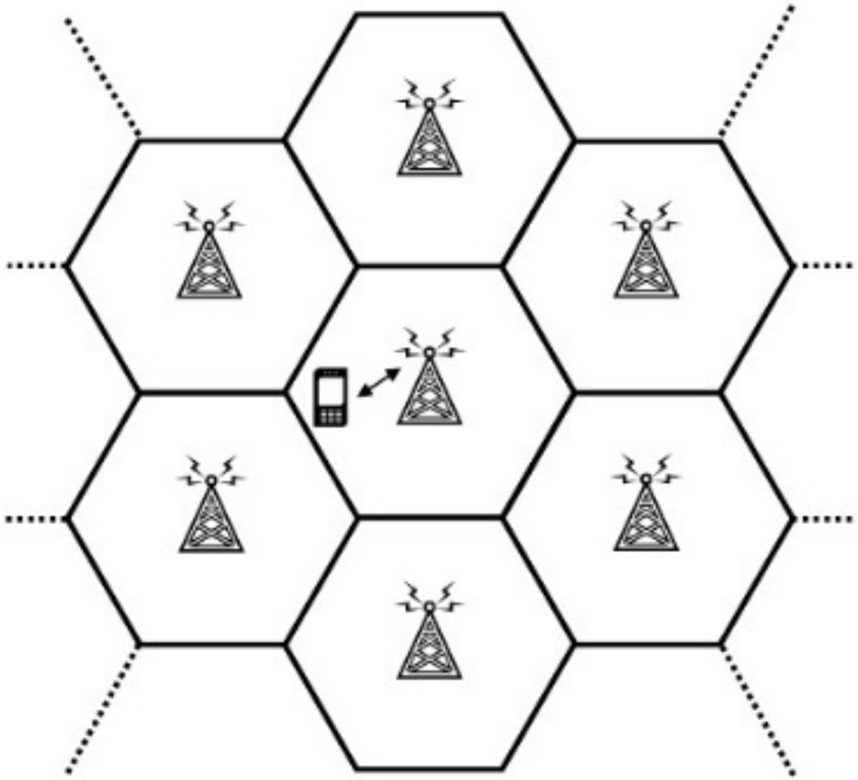


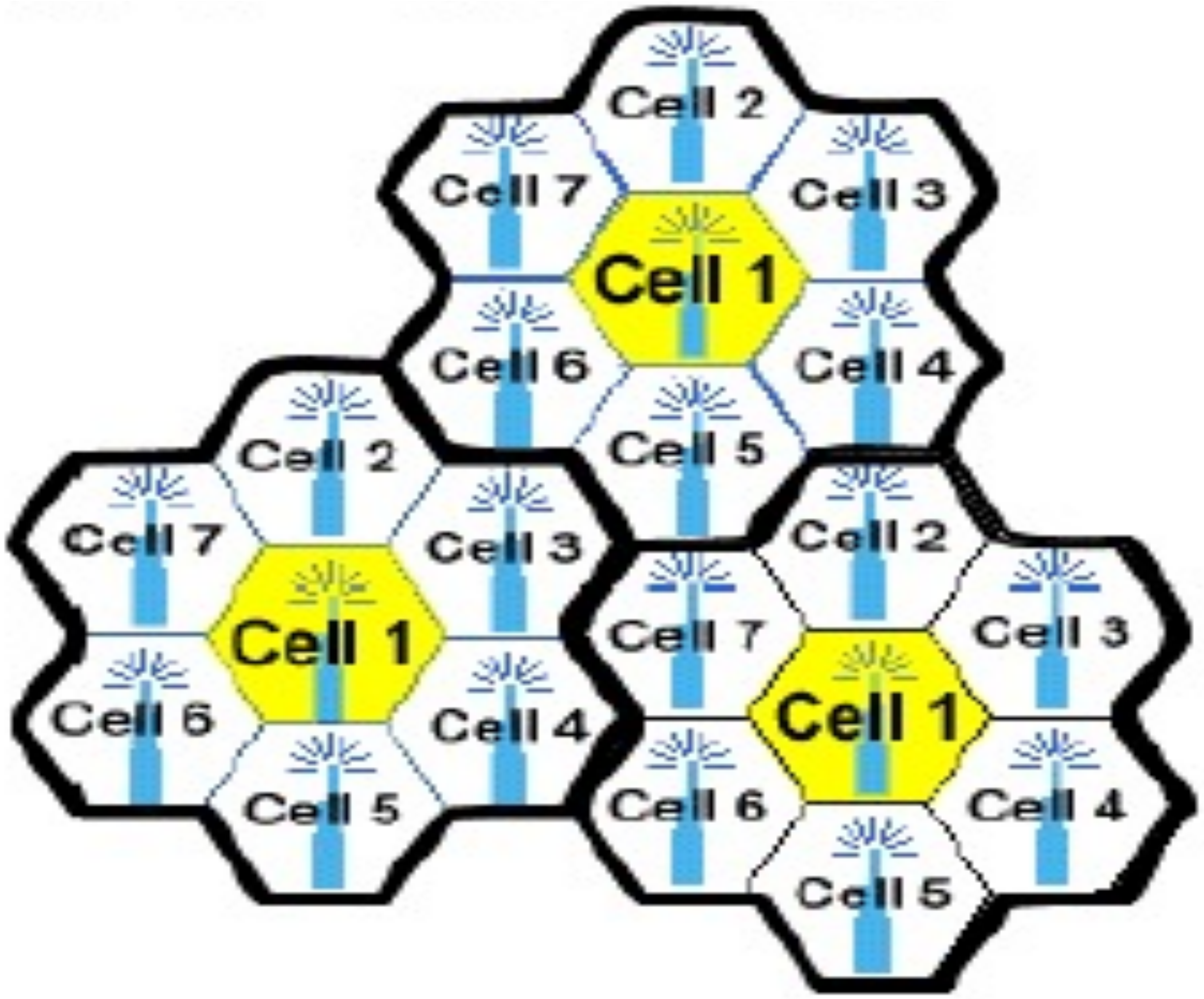
The Base Station (BTS)



Cellular Wireless System

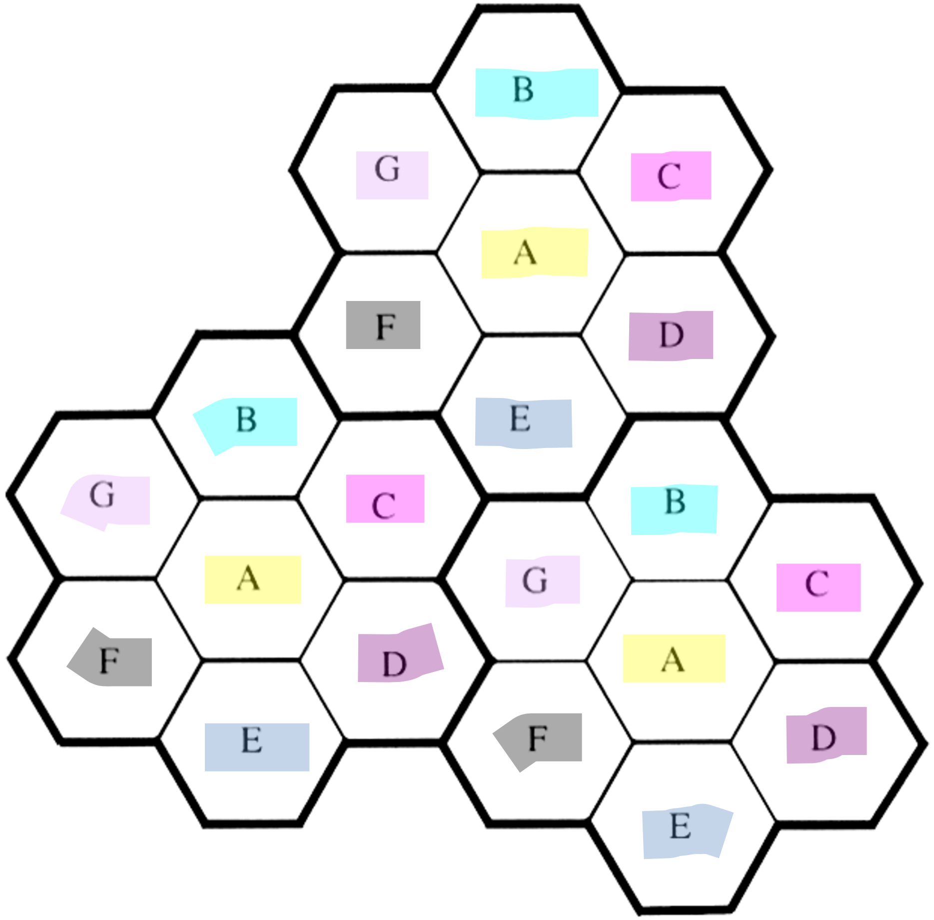
- A large geographical region is segmented into smaller “cell”s.
  - Transmit power limitation
  - Facilitates frequency spectrum re-use
- Cellular network design issues
  - Inter-cell synchronization
  - Handoff mechanism
  - Frequency planning



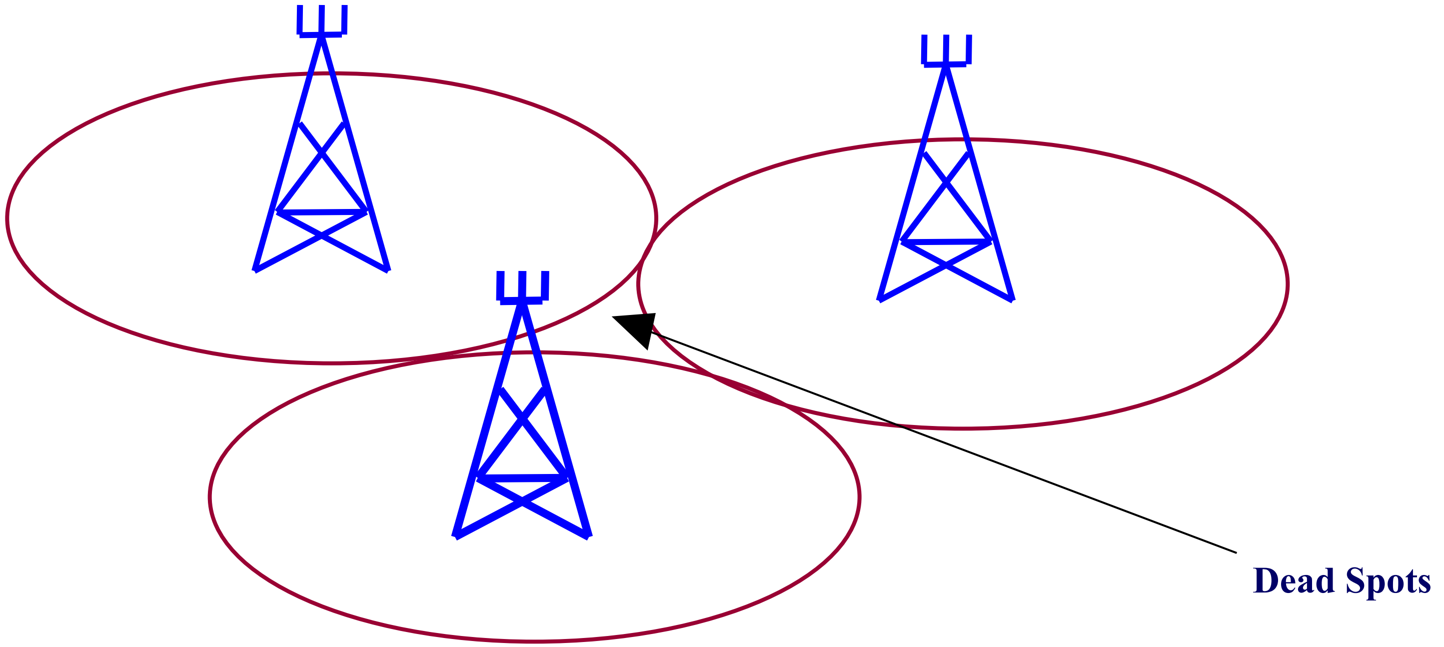


Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5
Cell 2
Cell 7
Cell 3
Cell 1
Cell 6
Cell 4
Cell 5

The Cellular Concept



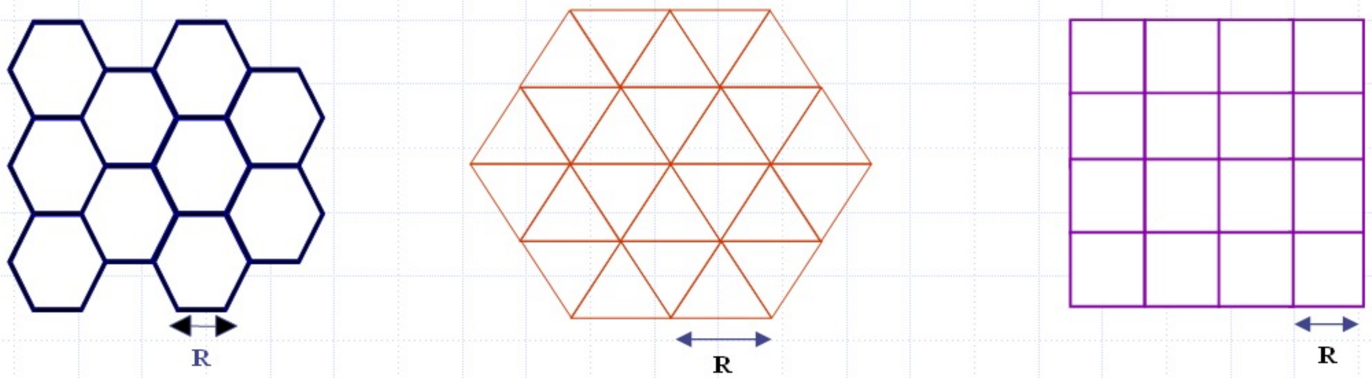
Cell Geometry, Radio Coverage



Problem of omni directional antennas

Cell Geometrical Shape

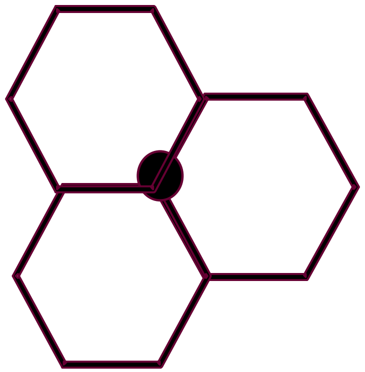
To solve the dead spot problem



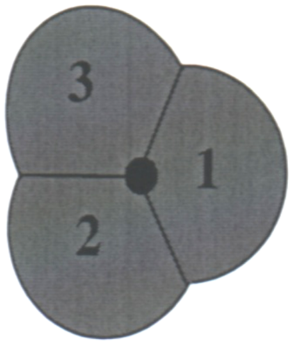
Tradeoffs

- The number of cells required to cover a given area.
- The cell transceiver power.

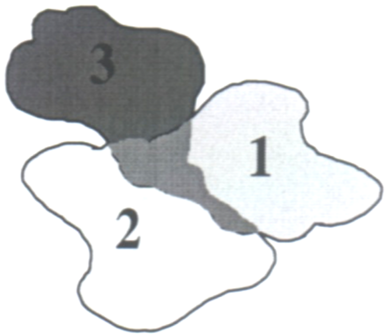
Sectorial Antenna



Sectorial Antenna



Theoretical

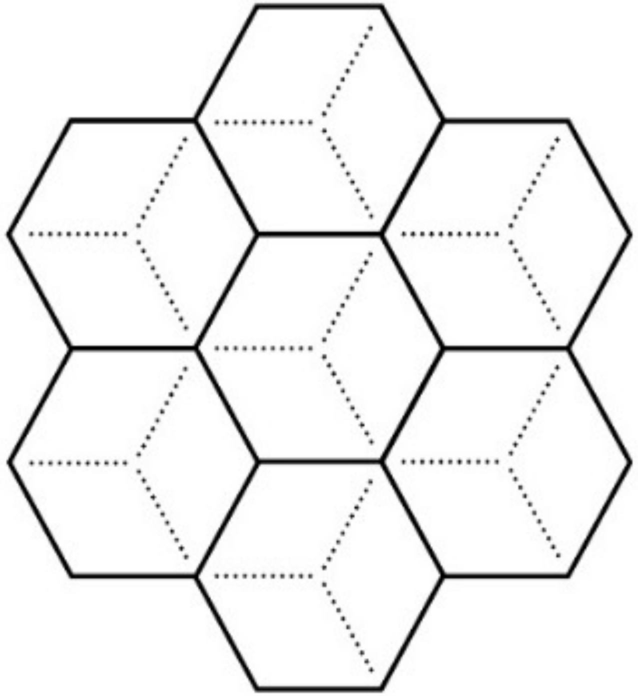


Actual

The cells will take the form of overlapping circles.

Due to the obstacles in the coverage area the actual shape of the cells would be Random.

- Sectorized cells



Cellular system

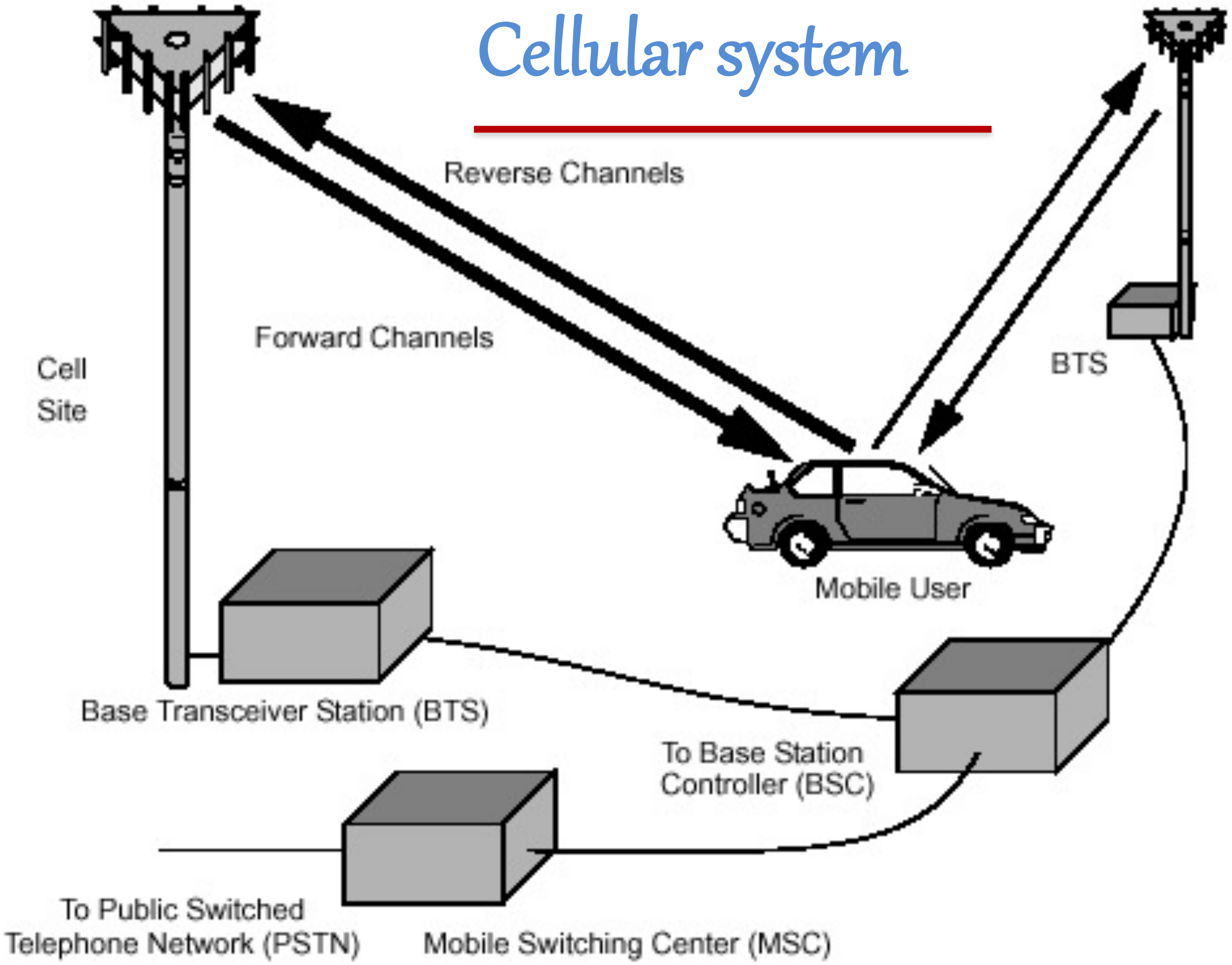


Figure 1–3 There are two main types of forward channels. Control and access channels are used to set up calls and provide security and management functions. Traffic channels are used to carry voice traffic. The reverse channels are also divided into access channels and traffic channels. In some systems, the Base Station Controller (BSC) may be integrated directly into the cell site. In other systems, as shown here, the Base Transceiver Stations (BTSs) are connected to a Base Station Controller.

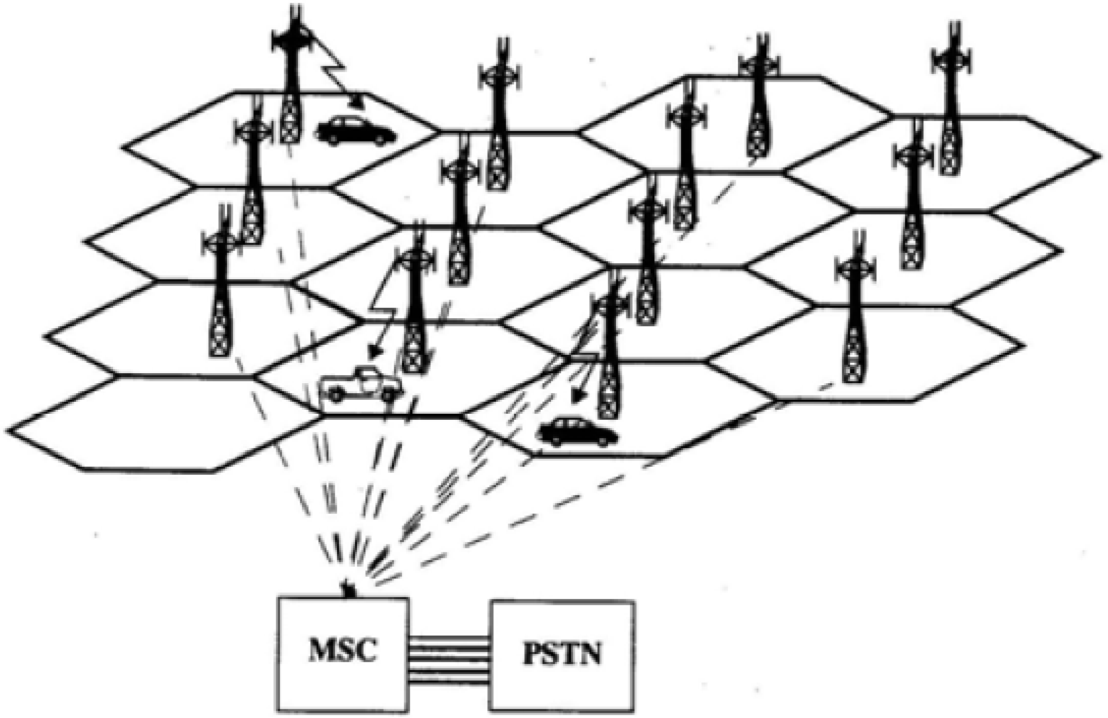


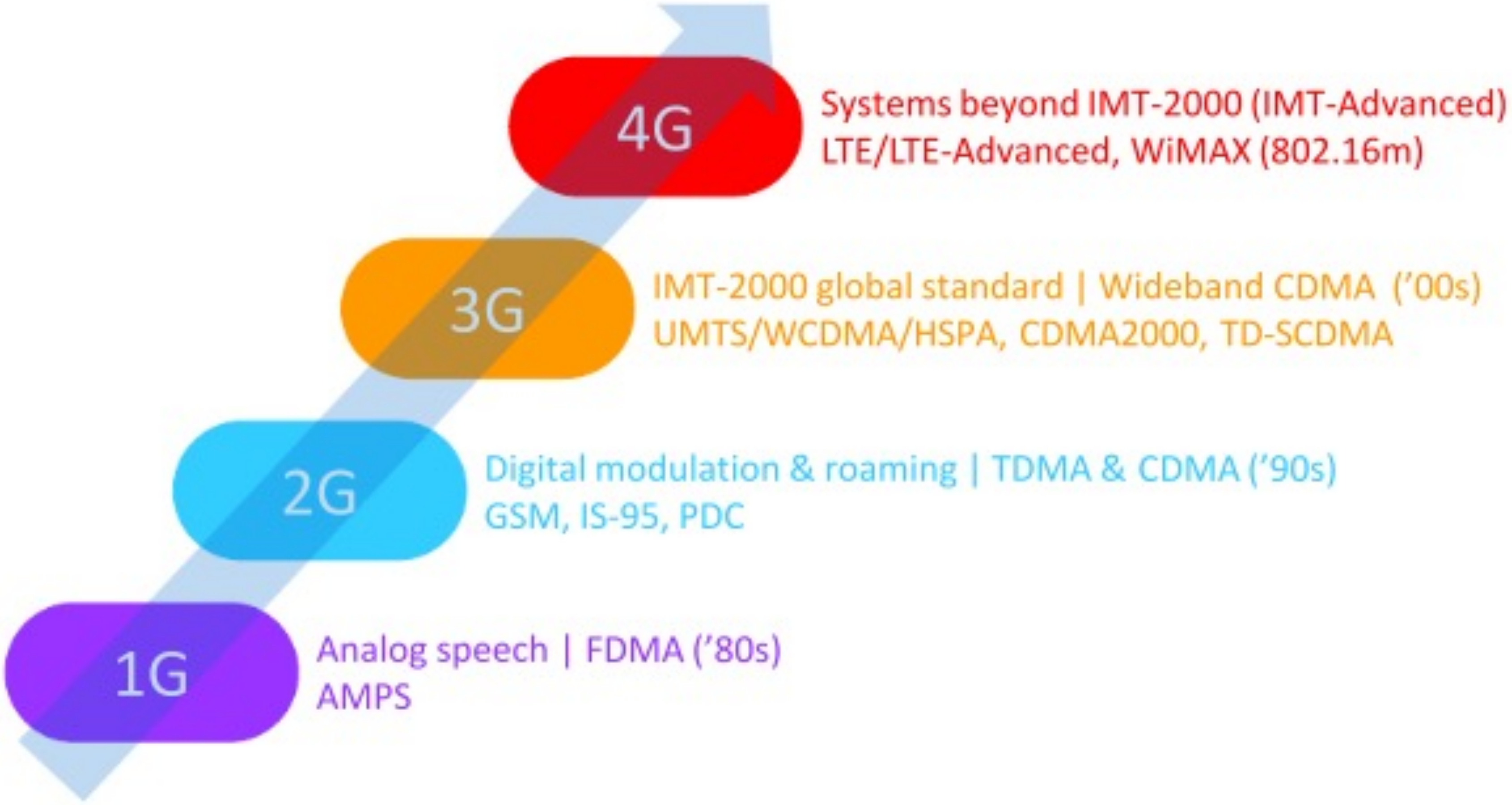
Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

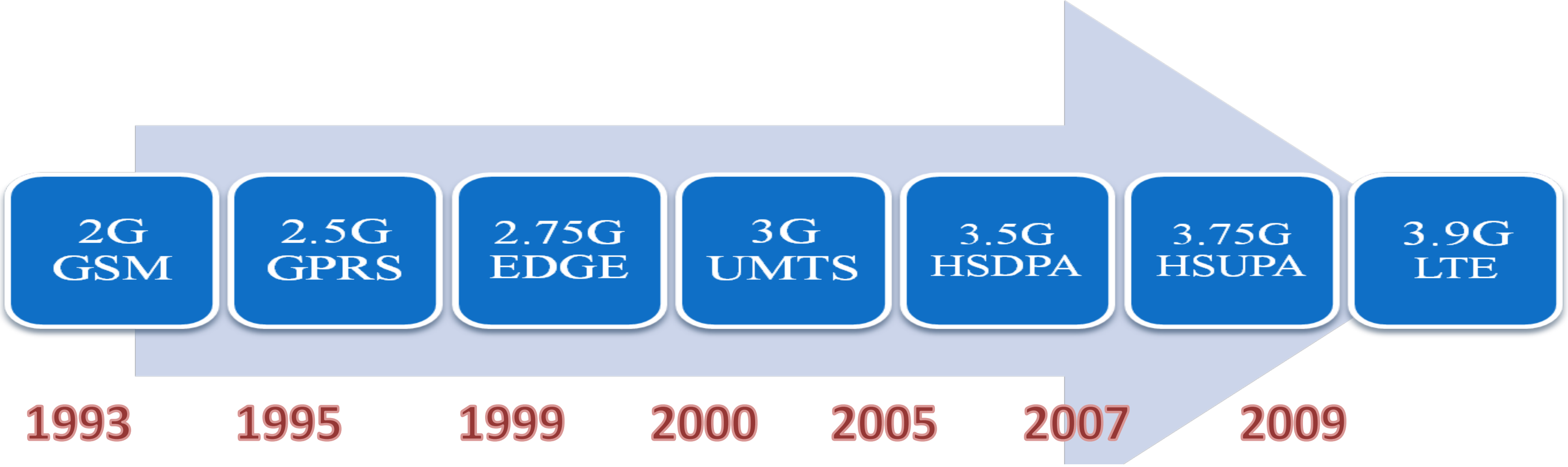
Evolution of Mobile Networks

	First Generation Systems	Second Generation Systems	Third Generation Systems
Time Frame	1984-1996	1996-2000	2000-2010
Services	Analog Mobile Telephony Voice Band Data	Digital voice, messaging	High speed data Broadband video Multimedia
Architecture	Macrocellular	Microcellular, Picocellular Wireless Local Loop	
Radio Technology	Analog FM, FDD-FDMA	Digital modulation, CDMA, TDMA using TDD and FDD	CDMA, possibly combined with TDMA, with TDD and FDD variants
Frequency Band	800 MHz	800+1900 MHz	2 GHz+
Examples	AMPS TACS ETACS NMT450/900 NTT JTACS/NTACS	cdmaOne (IS-95) GSM/DCS-1900 US TDMA IS-136 PACS PHS	cdma2000 WCDMA

By: Dr.Mohab Mangoud

Cellular system Evolution



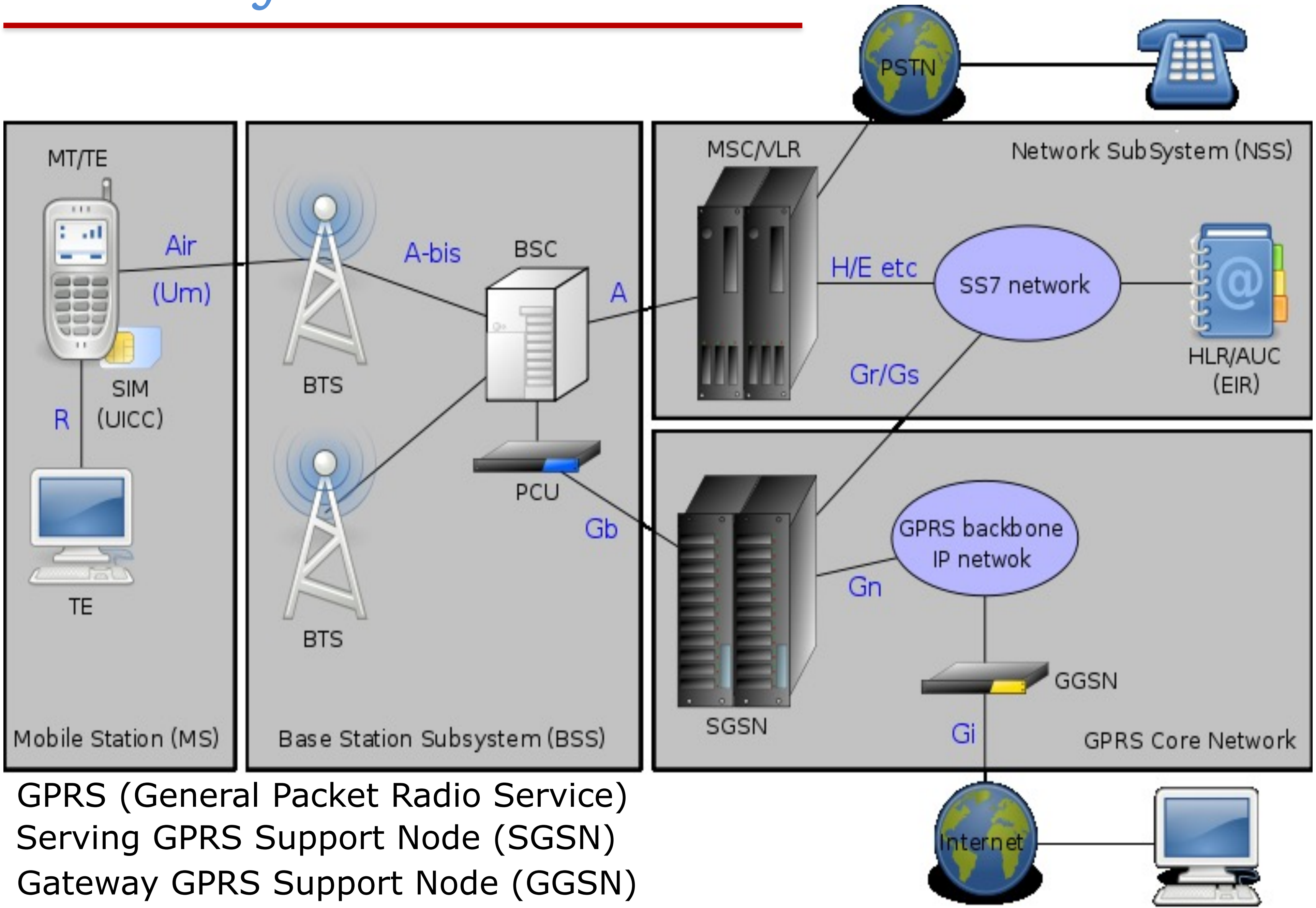


- 1G (Early 1980s)
  - Analog speech communications.
  - Analog FDMA.
  - Ex: AMPS
- 2G (Early 1990s)
  - Digital modulation of speech communications.
  - Advanced security and roaming.
  - TDMA and narrowband CDMA.
  - Ex: GSM, IS-95 (cdmaOne), and PDC
- 3G (Late 1990s)
  - Global harmonization and roaming.
  - Wideband CDMA
  - Ex: UMTS, cdma2000, and TD-SCDMA

- **2.5G – GPRS (General Packet Radio Service)**
- 2.75G- Enhanced Data Rates for GSM Evolution (EDGE)
- 3.5G- High Speed Downlink Packet Access (HSDPA)
- 3.75G- High Speed Uplink Packet Access (HSUPA)
- 3.9G- Evolved High Speed Packet Access (HSPA+)

Generation	Frequency	Definition	throughput	Technology
1G (1981-1996)	800-900 MHz (BW = 30 kHz)	Analog (FM) Voice	14.4 Kbps (peak)	AMPS, NMT, TACS ETACS
2G (1996-2000)	900/1800 MHz 850/1900 MHz (BW = 200KH)	Digital Narrowband Circuit Switching Data Voice Messaging (SMS)	9.6 / 14 Kbps	GSM/DCS - 1900 TDMA(IS-136) CDMA (IS95- CDMA-one)
2.5G, 2.75G		Packet Switching Data WAP +MMS	56 kbit/s up to 115 kbit/s	GPRS, EDGE
3G (2001-2010) (wideband-Global)	2GHz + 1920 - 2170MHz (BW=5MHz)	Digital Broadband Packet Switching Data (High speed data Multimedia)	3.1 Mbps (Peak) 500-700 Kbps	CDMA2000 (Verizon, Sprint) UMTS, WCDMA (AT&T, T-Mobile+ Europe)
3.5G 3.75G		>2 Mbps	14.4 Mbps (peak) 1-3 Mbps 42 Mbps (peak)& 28 Mbps → 2x2 MIMO 672 Mbps	HSPA: HSDPA, HSUPA HSPA+
4G (2012+) (Broadband) 5G=Gigabit	LTE (3GPP) LTE-A (3GPP2)	Digital Broadband All IP (voice+data) Very High Throughput	100-300 Mbps (peak) 100 -1000 Mbps (peak) 3-5 Mbps	LTE (WCDMA) Mobile WIMAX, IEEE802.16 (d,e,m) UBM (IP networks)

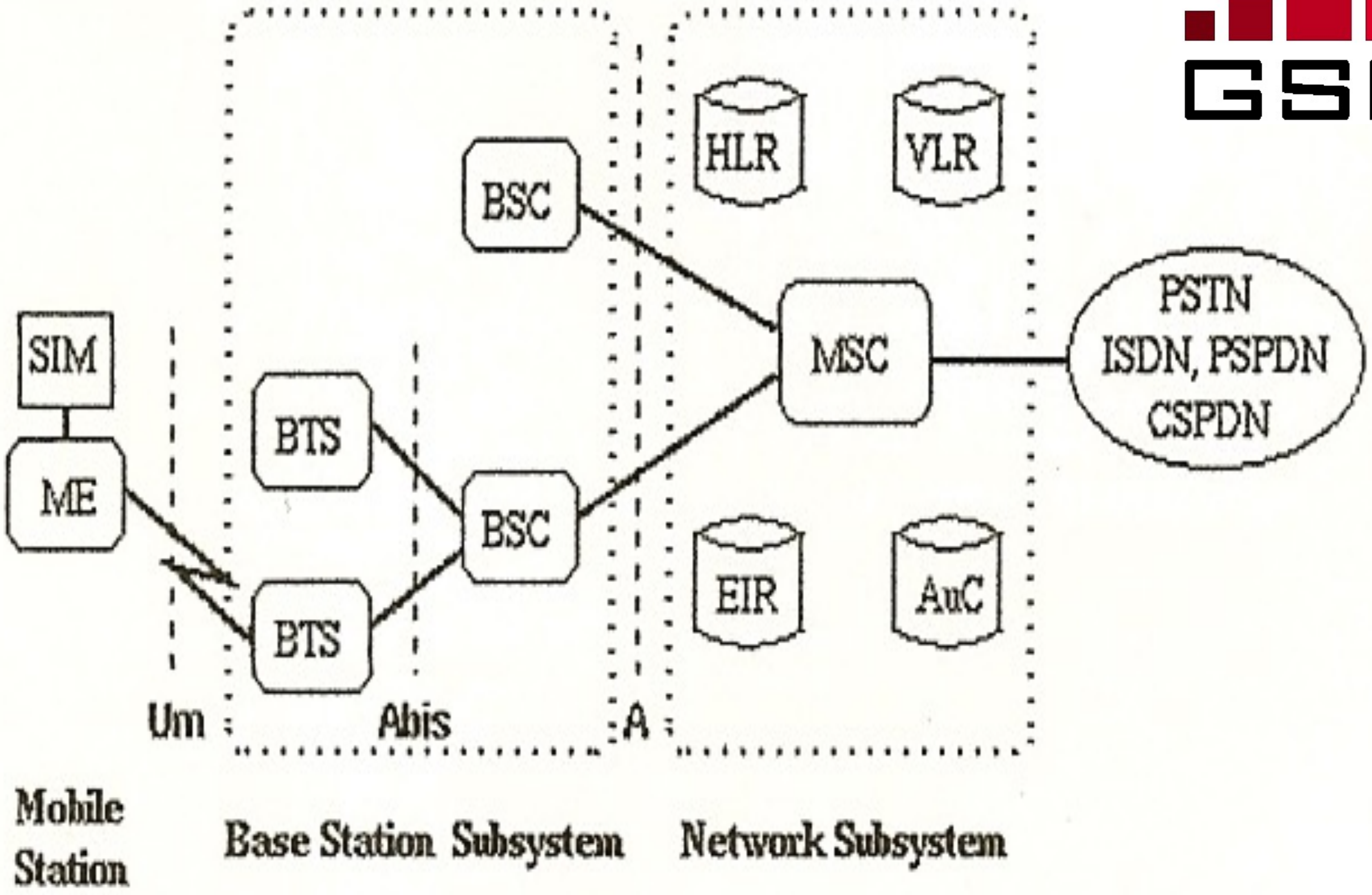
Structure of GSM Network



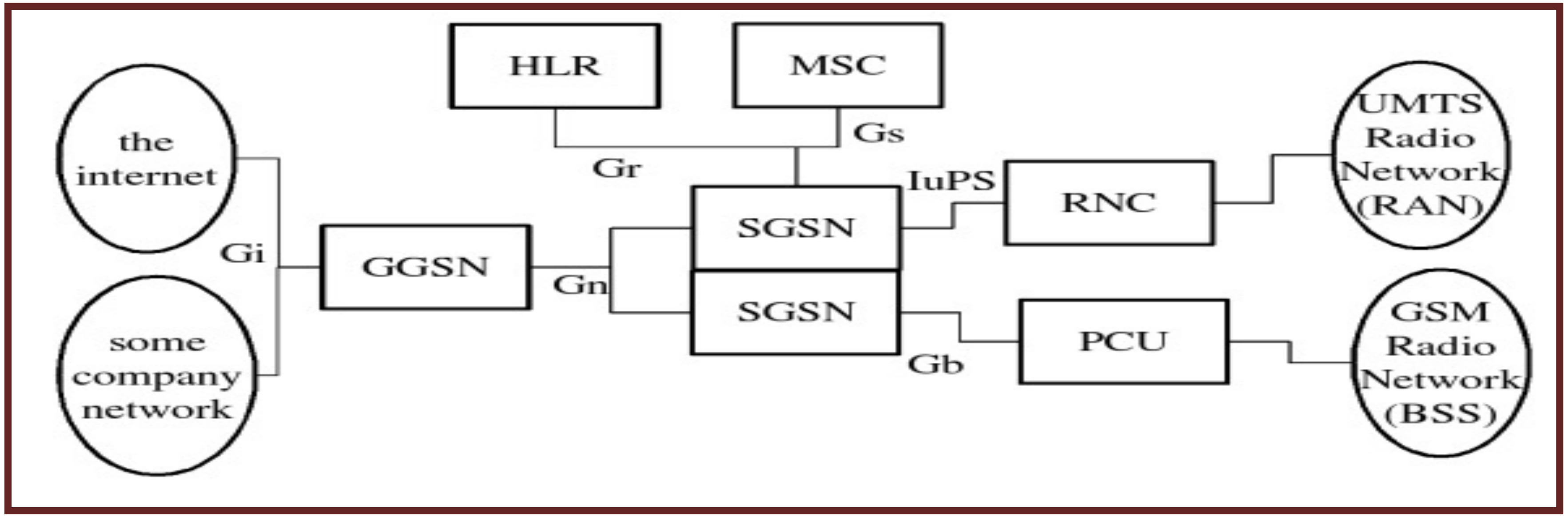
GPRS (General Packet Radio Service)
Serving GPRS Support Node (SGSN)
Gateway GPRS Support Node (GGSN)

System Architecture

- Mobile Station (MS)
  - Mobile Equipment (ME)
  - Subscriber Identity Module (SIM)
- Base Station Subsystem (BBS)
  - Base Transceiver Station (BTS)
  - Base Station Controller (BSC)
- Network Subsystem
  - Mobile Switching Center (MSC)
  - Home Location Register (HLR)
  - Visitor Location Register (VLR)
  - Authentication Center (AUC)
  - Equipment Identity Register (EIR)



SIM Subscriber Identity Module	BSC Base Station Controller	MSC Mobile services Switching Center
ME Mobile Equipment	HLR Home Location Register	EIR Equipment Identity Register
BTS Base Transceiver Station	VLR Visitor Location Register	AuC Authentication Center



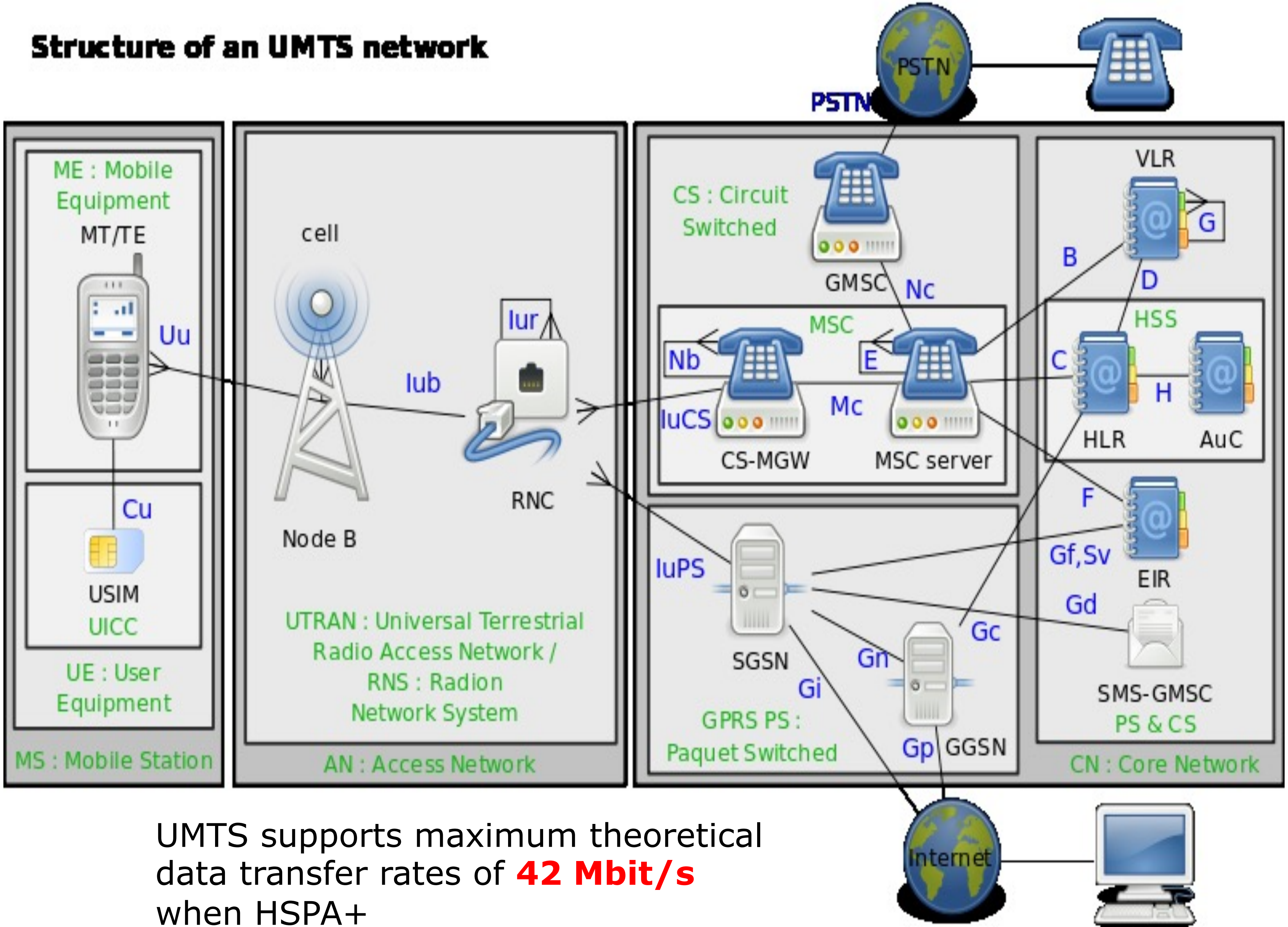
The GPRS core network is the central part which allows 2G, 3G and WCDMA mobile networks to transmit IP packets to external networks such as the Internet provides mobility management, session management and transport for Internet Protocol packet services in GSM and WCDMA networks.

Gateway GPRS Support Node (GGSN): is responsible for the interworking between the GPRS network and external packet switched networks

Serving GPRS Support Node (SGSN): is responsible for the delivery of data packets from and to the mobile stations within its geographical service area.

Packet control unit: The allocation of channels between voice and data is controlled by the base station, but once a channel is allocated to the PCU, the PCU takes full control over that channel.

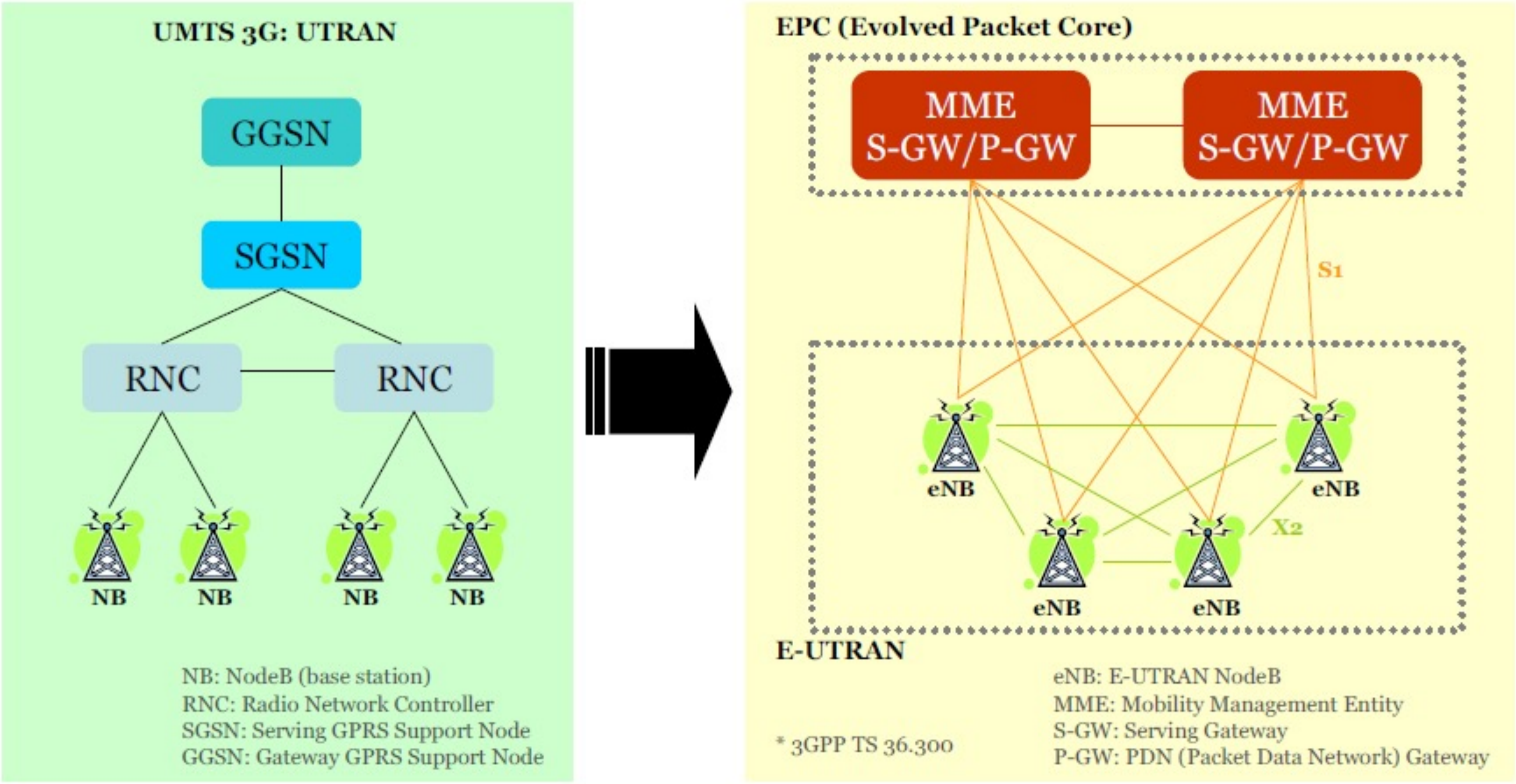
The Radio Network Controller (or RNC): is a governing element in the UMTS radio access network (UTRAN) and is responsible for controlling the Node Bs that are connected to it..



UMTS supports maximum theoretical data transfer rates of **42 Mbit/s** when HSPA+

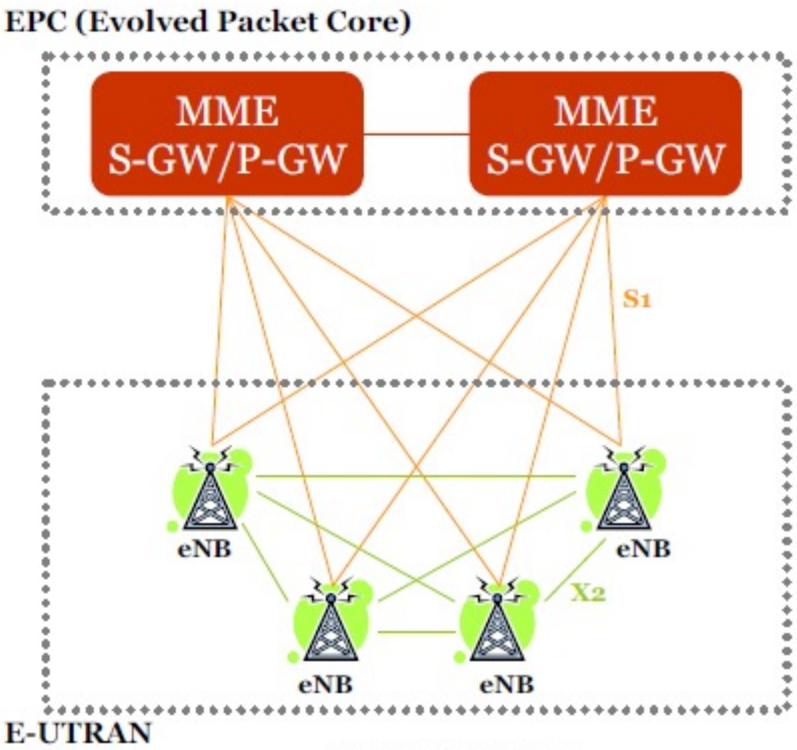
LTE Network Architecture

- E-UTRAN (Evolved Universal Terrestrial Radio Access Network)



LTE Network Architecture

- eNB
  – All radio interface-related functions
- MME
  – Manages mobility, UE identity, and security parameters.
- S-GW
  – Node that terminates the interface towards E-UTRAN.
- P-GW
  – Node that terminates the interface towards PDN.



* 3GPP TS 36.300

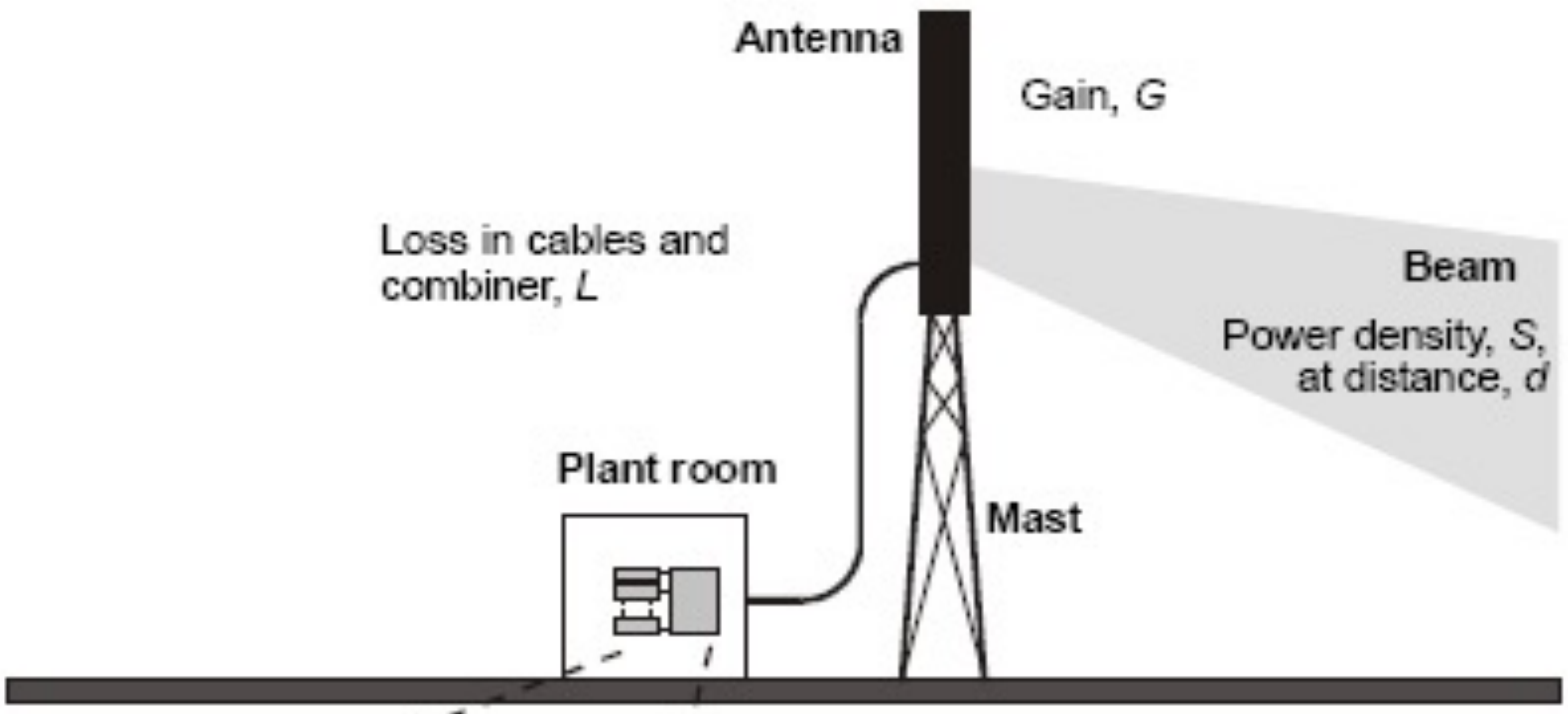
eNB: E-UTRAN NodeB
MME: Mobility Management Entity
S-GW: Serving Gateway
P-GW: PDN (Packet Data Network) Gateway

Types and Structure of Base Station

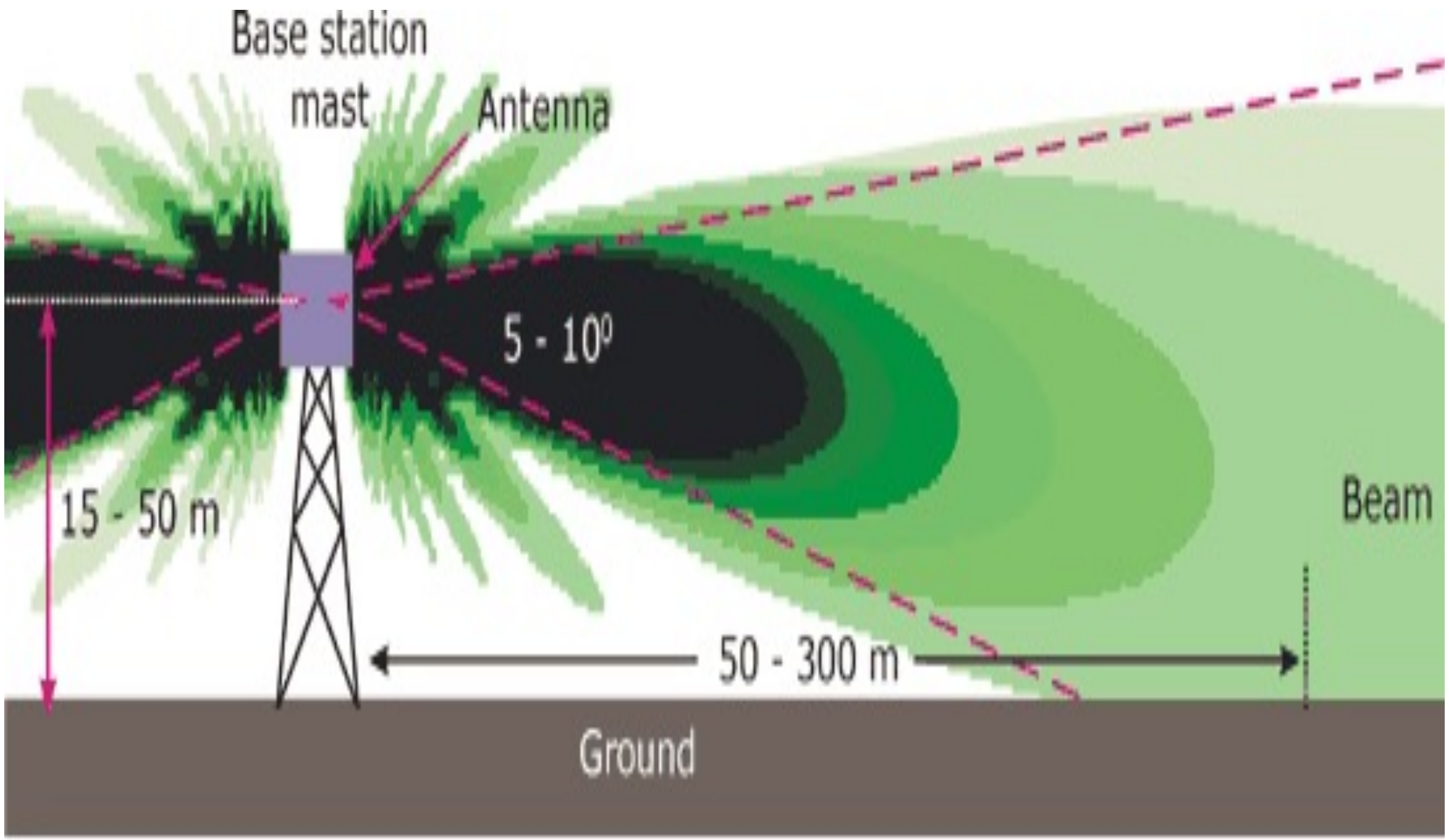
types of Base stations:

- Macro-cell
- Micro-cells
- Pico-cell
- Femto cell

The base station consists of : **plants room, mast, Antenna and cables.**



RF Beamfrom the Base Station



Base Station Antenna 1800 MHz PCS & GSM (Sectored cells)

Frequency Range	1710-1990 MHz
Bandwidth	170 MHz
Gain	12.5 dBi
VSWR	≤ 1.5
Nominal Impedance	50 ohm
Polarization	Vertical
Maximum Power	100 W
Connector	N Female
3dB Beamwidth Horizontal Plane	120°
3dB Beamwidth Vertical Plane	16°
F/B	> 25 dB
Dimension	600 x 100 x 80 mm
Weight	6 kg / 13.23 lb

Main characteristics of a GSM hand-held terminal transmitter

	GSM 900	DCS 1800
Frequency band	890 – 915 MHz	1710 – 1785 MHz
Channel width	200 kHz	200 kHz
Peak radiated power	2 W	1 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK
Maximum average radiated power	250 mW	125 mW

Main characteristics of a GSM base-station transmitter

	GSM 900	DCS 1800
Frequency band	935 – 960 MHz	1805 – 1880 MHz
Channel width	200 kHz	200 kHz
Peak radiated power (typical)	30 W	30 W
Multiple access technique	FDMA + TDMA	FDMA + TDMA
Modulation scheme	GMSK	GMSK

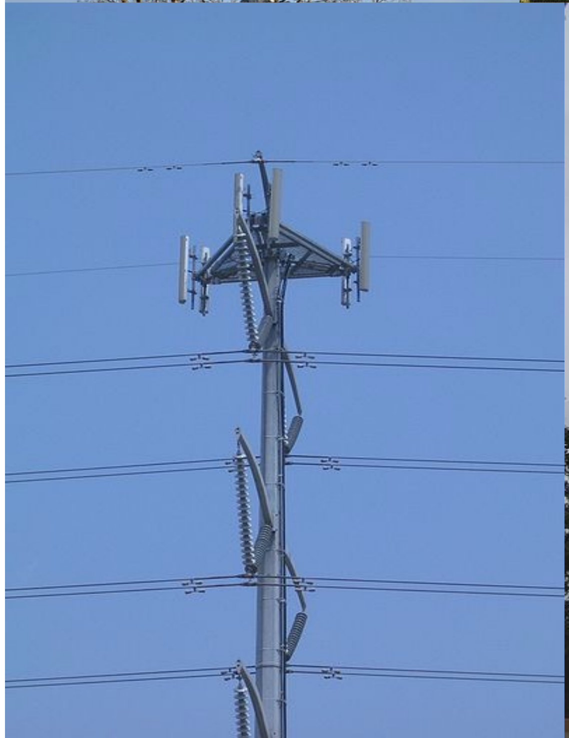

base station antenna in Mexico City, Mexico.
There are three antennas: each serves a 120-degree segment of the horizon.
The microwave dish links the site with the telephone


492 F High Point Road in Gaffney, South Carolina.

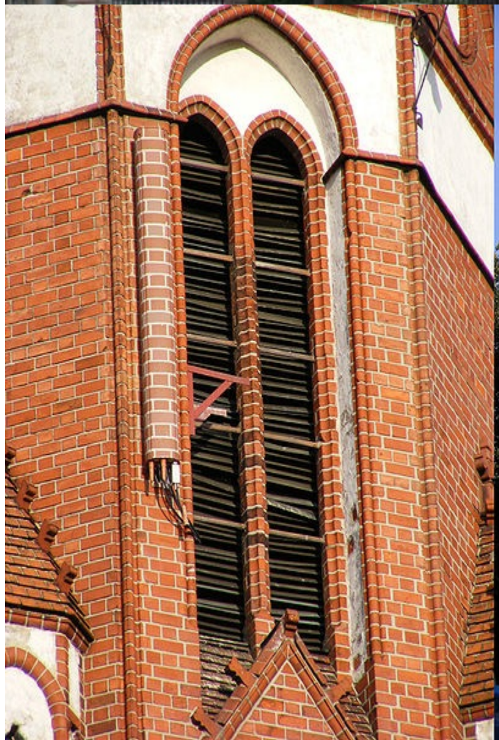

Two GSM base stations disguised as trees in Dublin, Ireland.


Cell tower disguised as a palm tree in Tucson, Arizona







Fundamental Constraints

- Shannon's capacity upper bound
  - Achievable data rate is fundamentally limited by bandwidth and signal -to-noise ratio (SNR).

Signal power

$$C = BW \cdot \log_2\left(1 + \frac{S}{N}\right) \text{ [bits per second]}$$

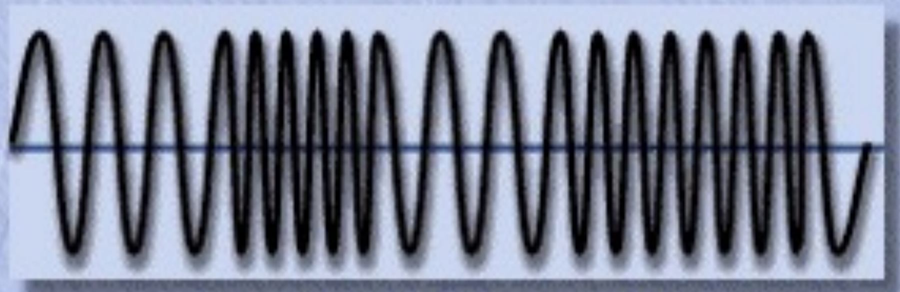
Channel bandwidth

Noise power

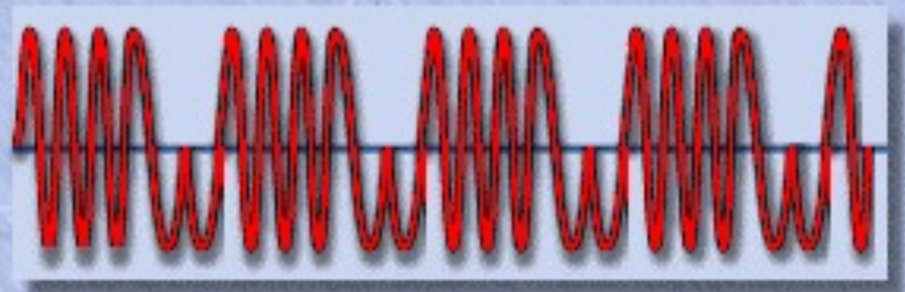
$$\eta = \frac{\text{Transmission Rate}}{\text{Channel Bandwidth } W} \ [\text{bits}/s/Hz].$$

- PSK requires too wide a bandwidth
- Gaussian Minimum Shift Keying (GMSK) is actually used on the GSM air interface

AMPLITUDE MODULATION



FREQUENCY MODULATION



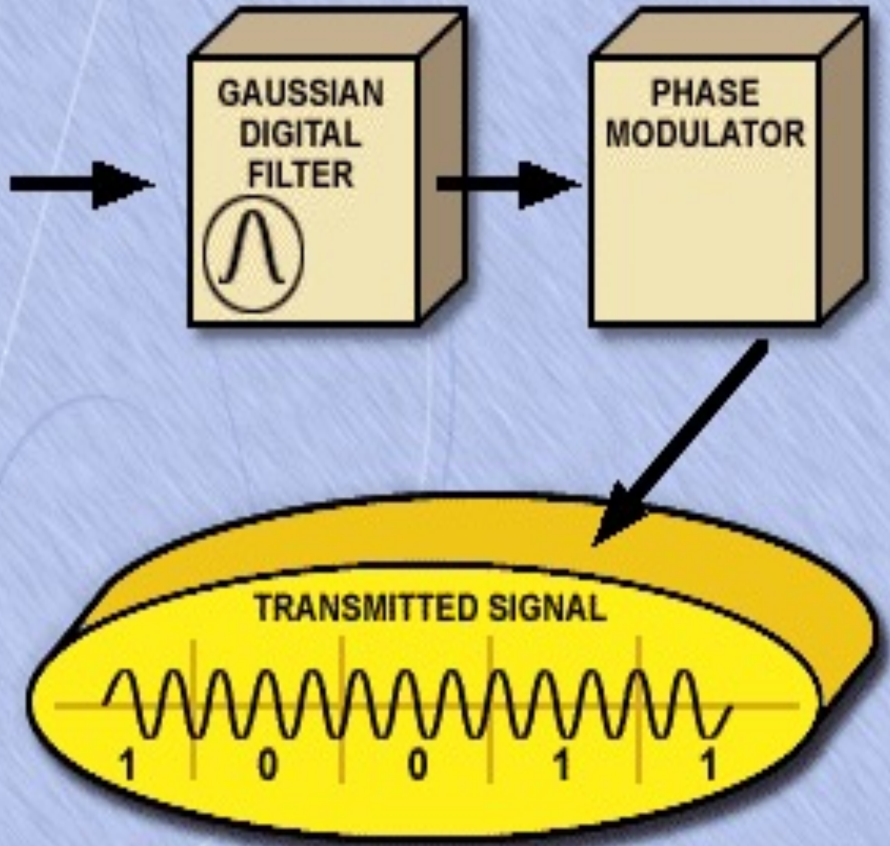
PHASE SHIFT KEYING (PSK)

MOTOROLA

By: Dr.Mohab Mangoud

Gaussian Minimum Shift Keying:

- Digital signal filtered through a Gaussian Filter
- Filtering distorts the signal, rounding off the corners and removing abrupt phase changes
- Distorted signal is used to phase shift the carrier signal
- Phase change occurs over a period of time
- Frequency components are lowered, reducing the bandwidth requirement

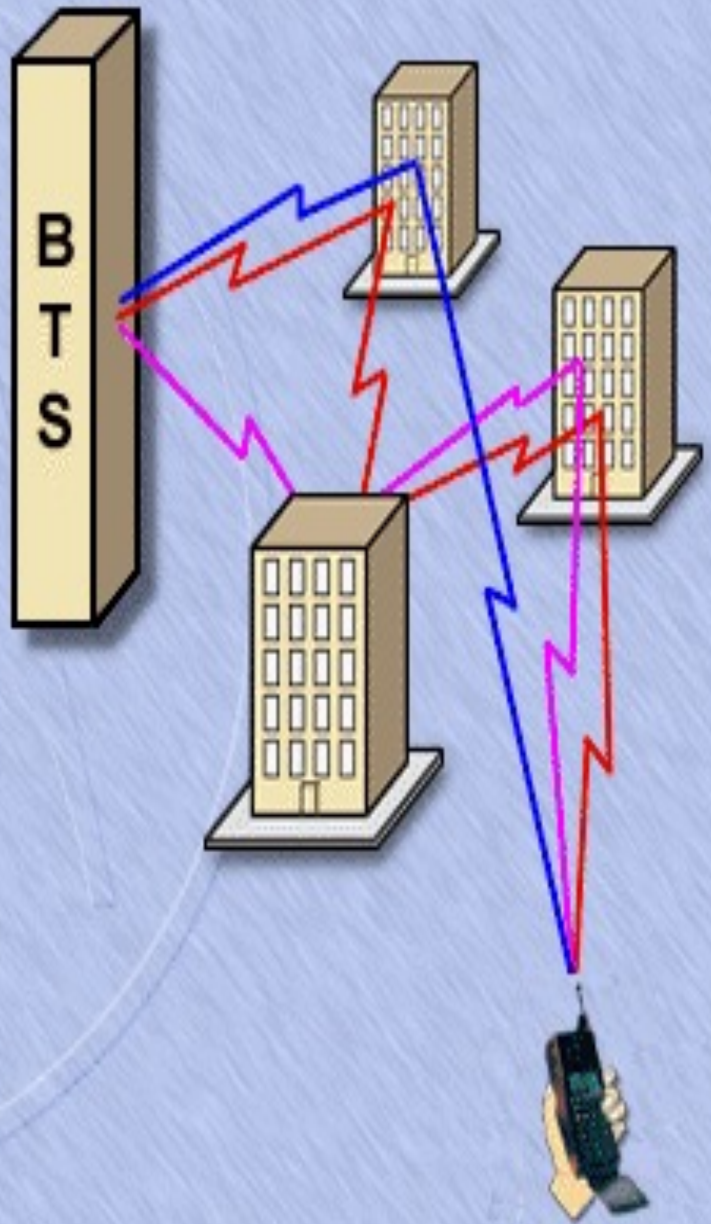


MOTOROLA

By: Dr.Mohab Mangoud

MULTIPATH FADING

- Signals travel from transmitter to receiver by different routes and experience time dispersion
- Signals combine again at receiver, constructively or destructively
- Combined signal strength also changes when receiver moving



By: Dr.Mohab Mangoud

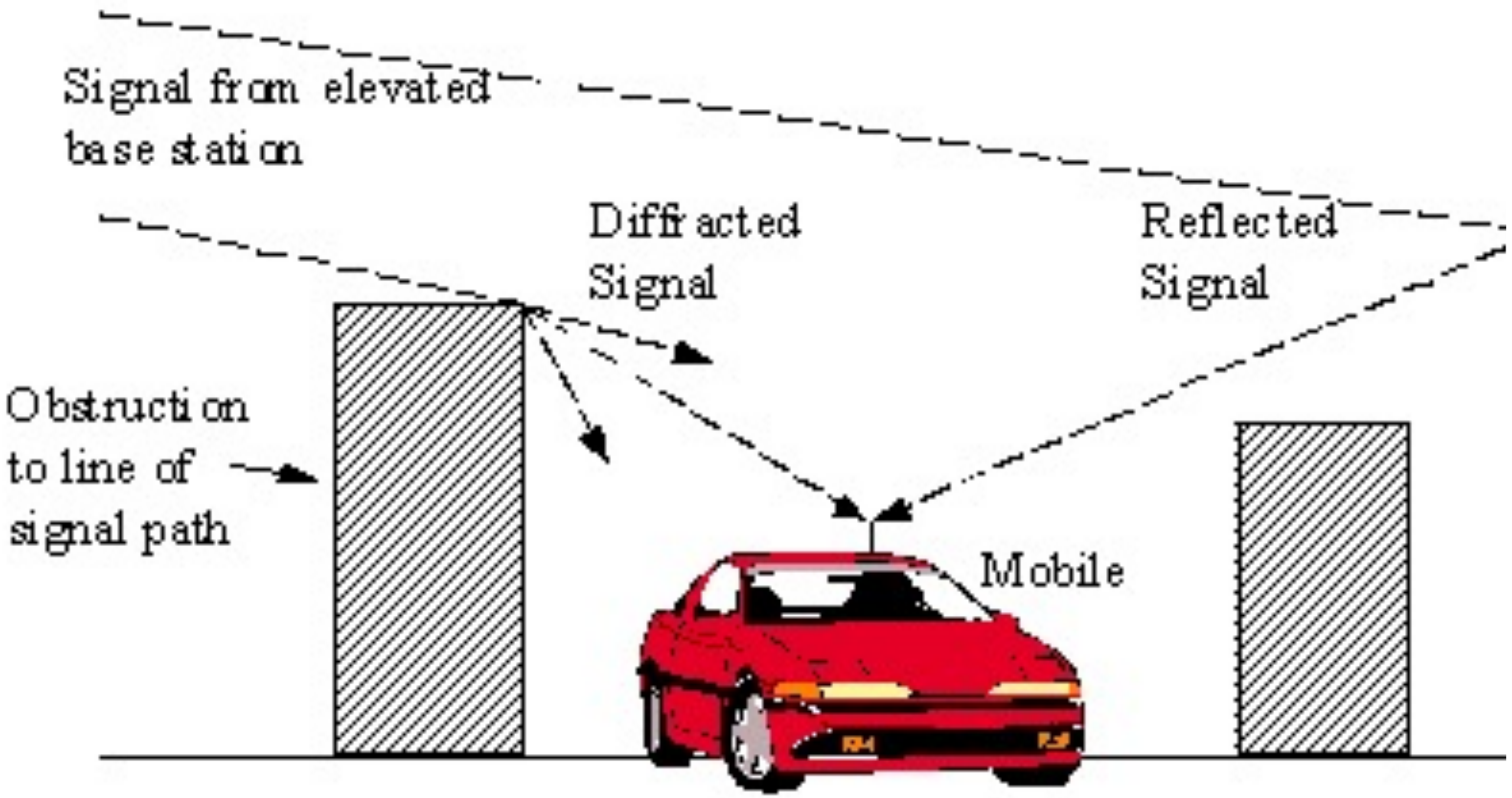


Figure 2 Radio Propagation Effects

- GSM combats multipath fading with:
  - Equalisation
  - Diversity
  - Frequency Hopping
  - Interleaving
  - Channel Coding

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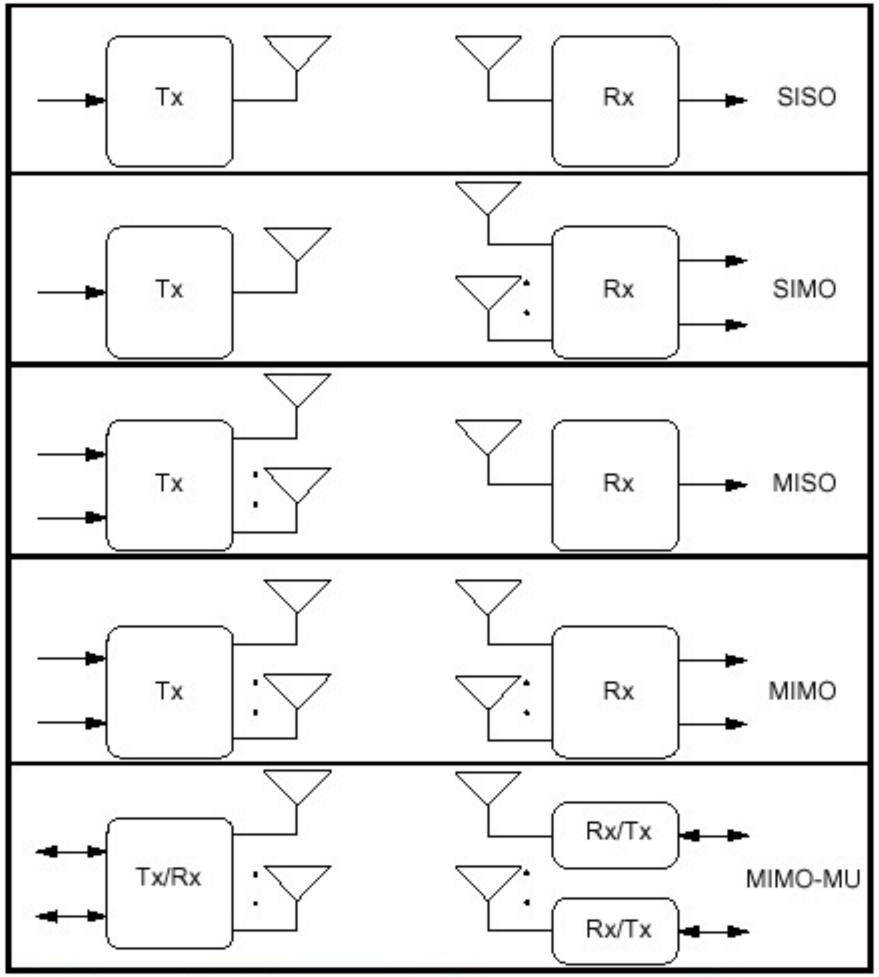


SISO: Single input Single output
SIMO: Single input Multiple output
MISO: Multiple input Single output
MIMO: Multiple input Multiple output
MIMO-MU: Multiple input Multiple output (multiuse

By: Dr.Mohab Mangoud

Smart antennas & Beamforming

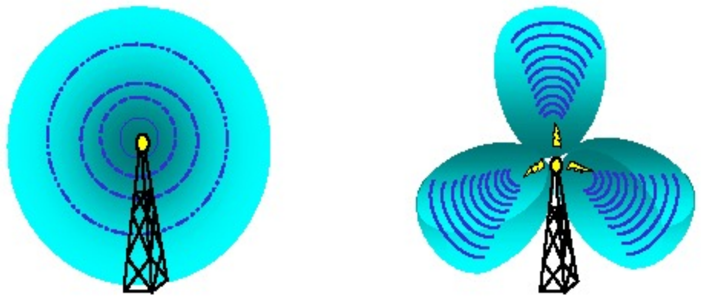
- Traditional cellular systems
- Idea of smart antenna

It consists of

a number of radiating elements (antenna array)

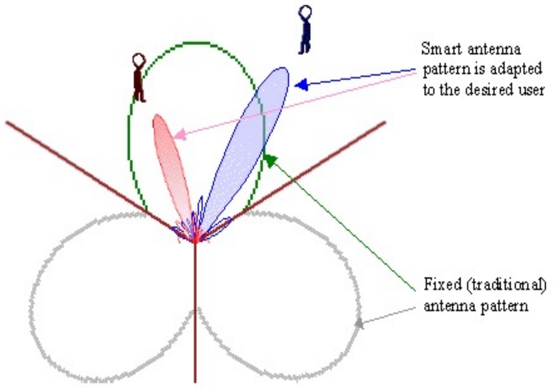
a combining/dividing network (Beamforming unit)

control unit, realized using DSP



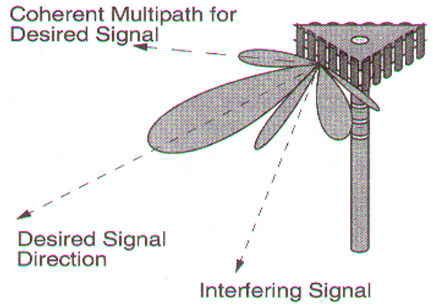
Omnidirectional antenna

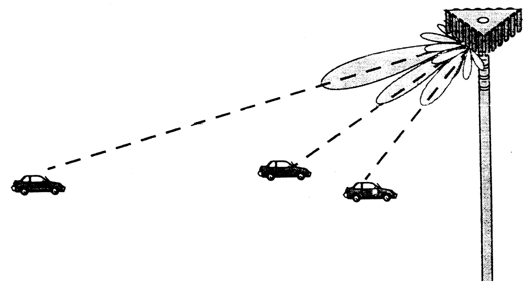
Multibeam antenna array



Beamforming

- to increase the system capacity and to increase the signal quality (system performance
- to avoid problems associated with multipath





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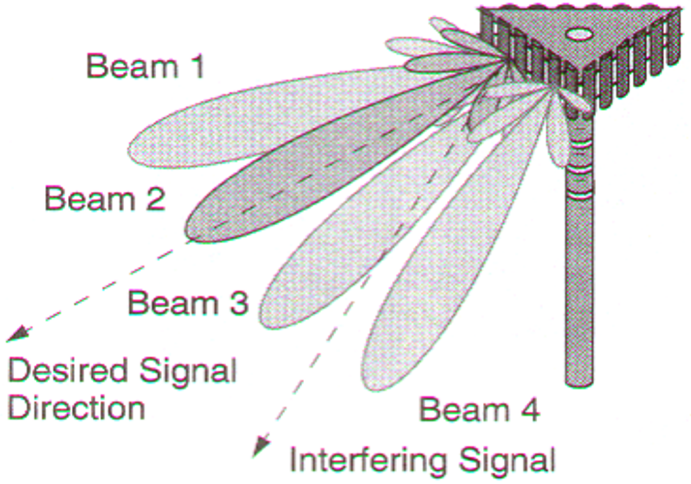
Types of Smart Antennas

Switched-Beam Antennas

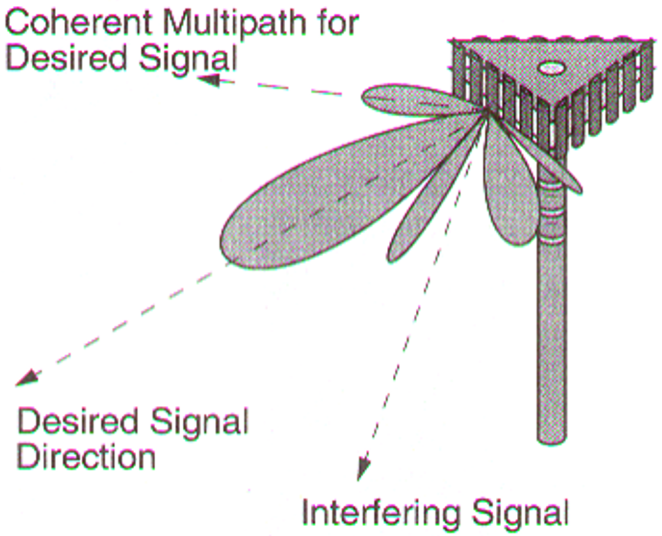


•Disadvantages:

Signal strength degradation

The desired signal and interfering signals can not be distinguished (Reduced S/N)

Adaptive-Array Antennas

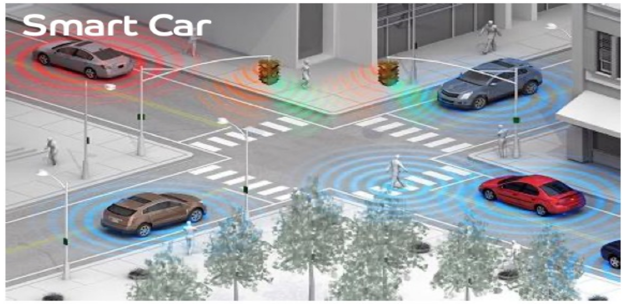


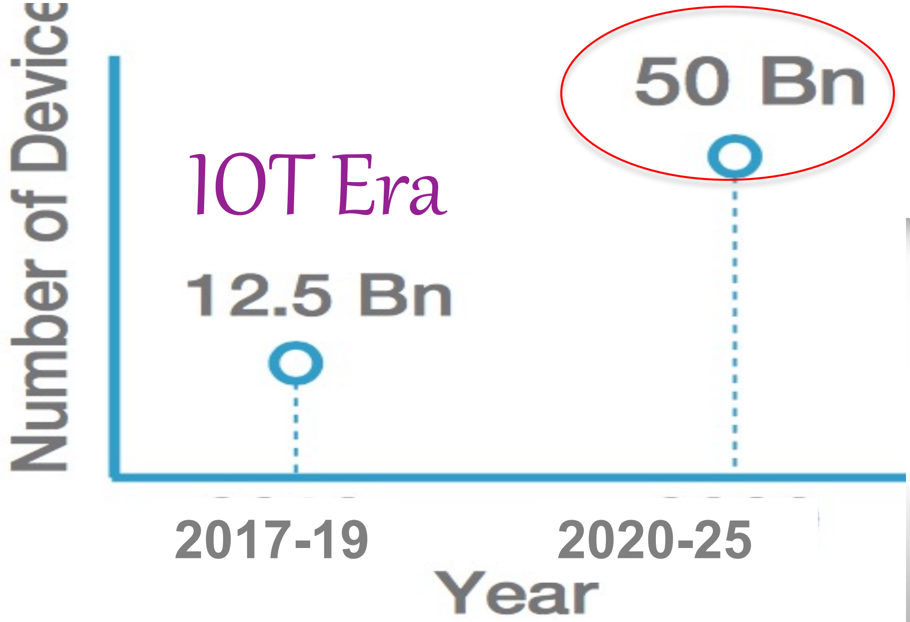
•A direction of arrival (DOA) algorithm for determining signal direction & interference sources is needed.

•The beam pattern is adapted (steered) based on changed in both the desired and interfering signal locations.

By: Dr.Mohab Mangoud

5G





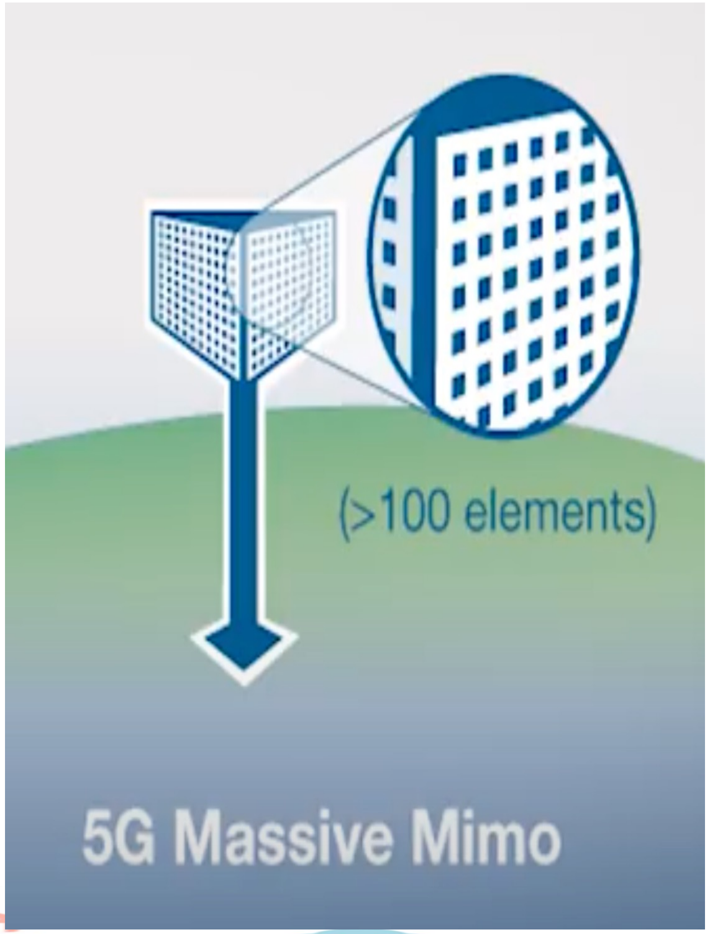
Source: 5G Samsung Report

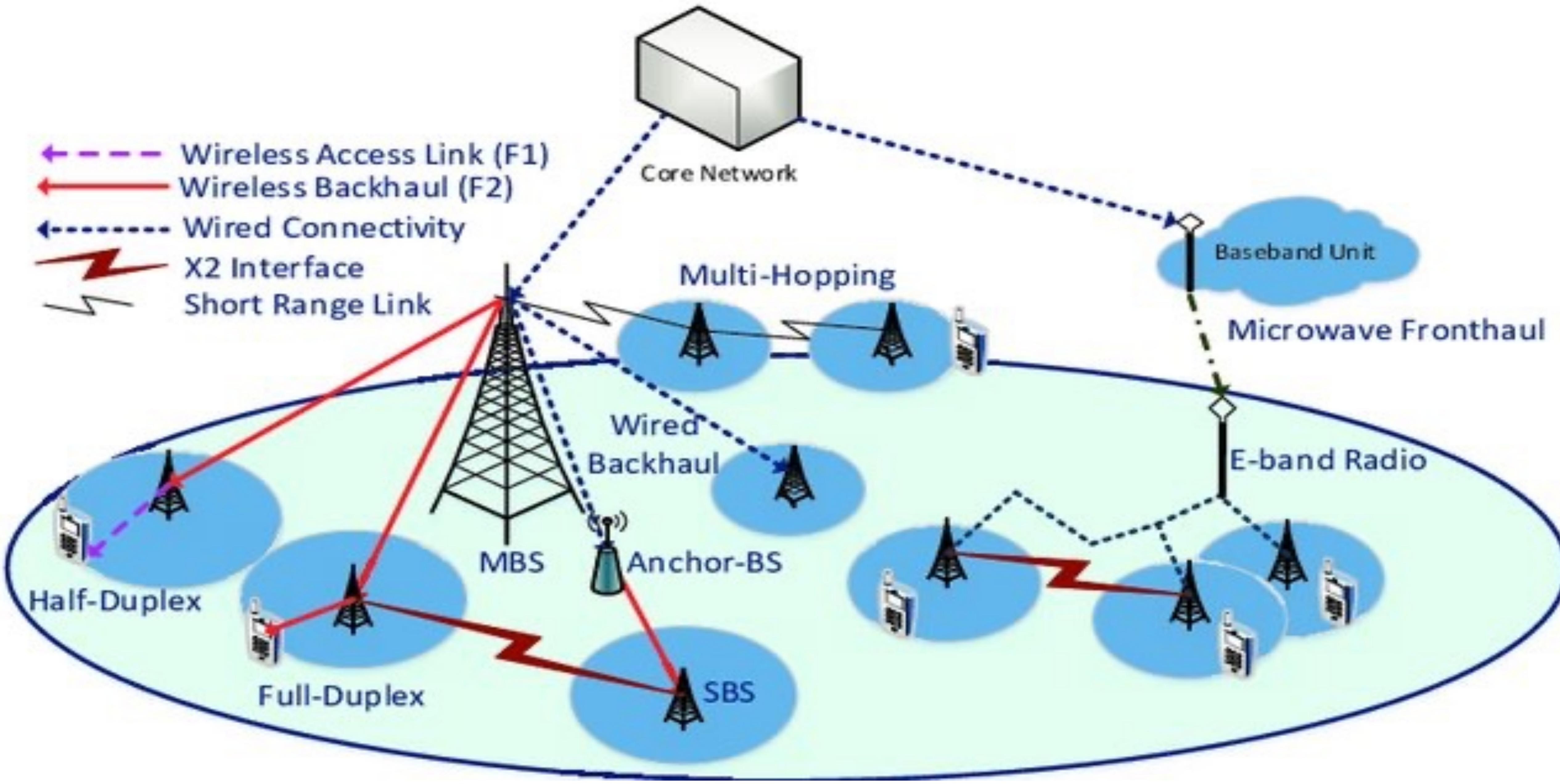
Exabytes = 10^{18} = one bilion of gigabytes


NETWORK SLICING
Gigabytes
in a second
Industry
automation
Self Driving Car
HOTEL
HOSPITAL
eHealth
Voice
Work and play
in the cloud
Augmented reality
3D video, UHD screens

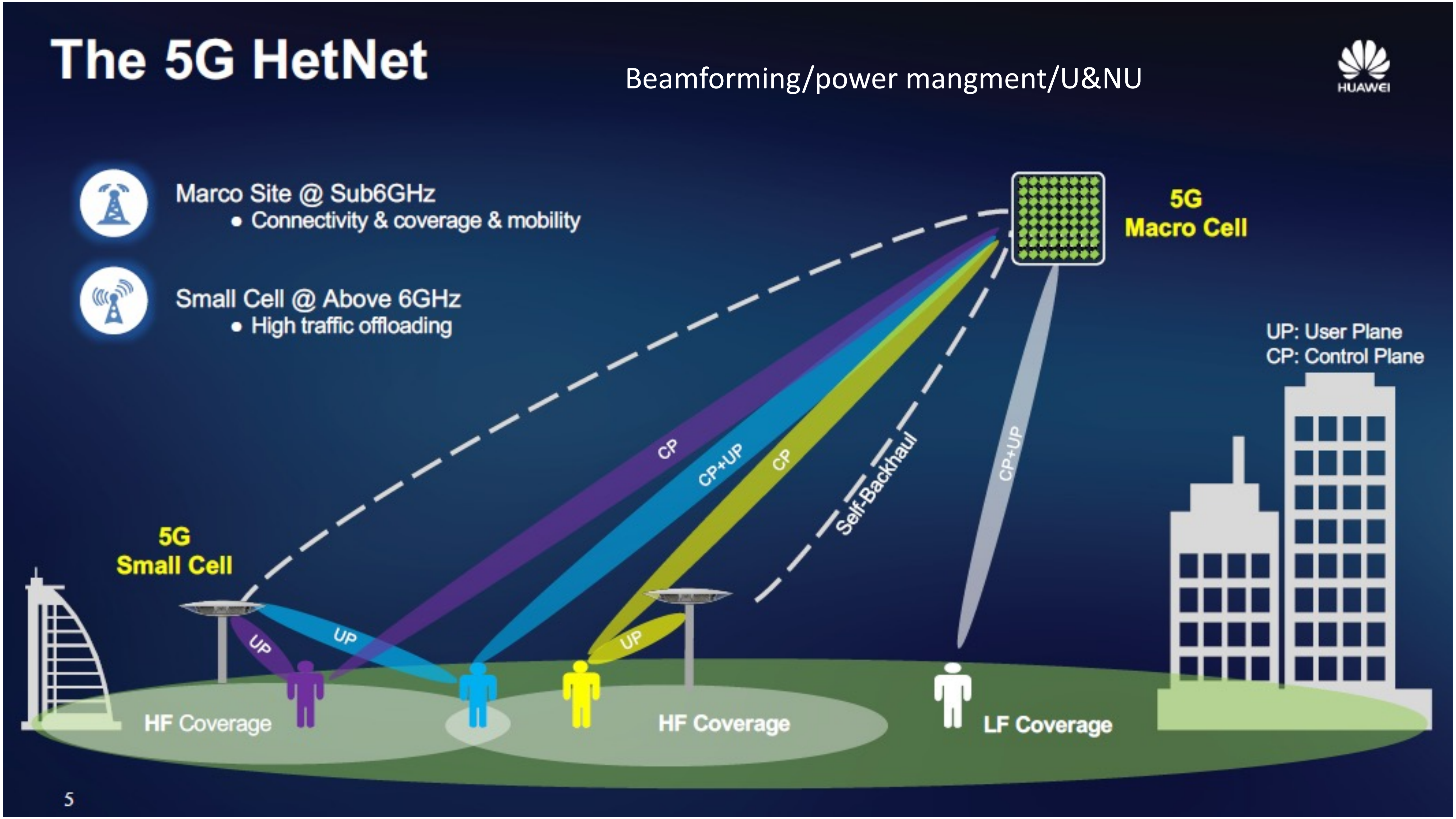
Key Technologies of 5G & IoT

- Millimeter waves
- Massive MIMO
- Multi-RAT (Radio Access Technology)
- Advanced D2D (Device to Device), M2M
- Dense Small Cell deployment



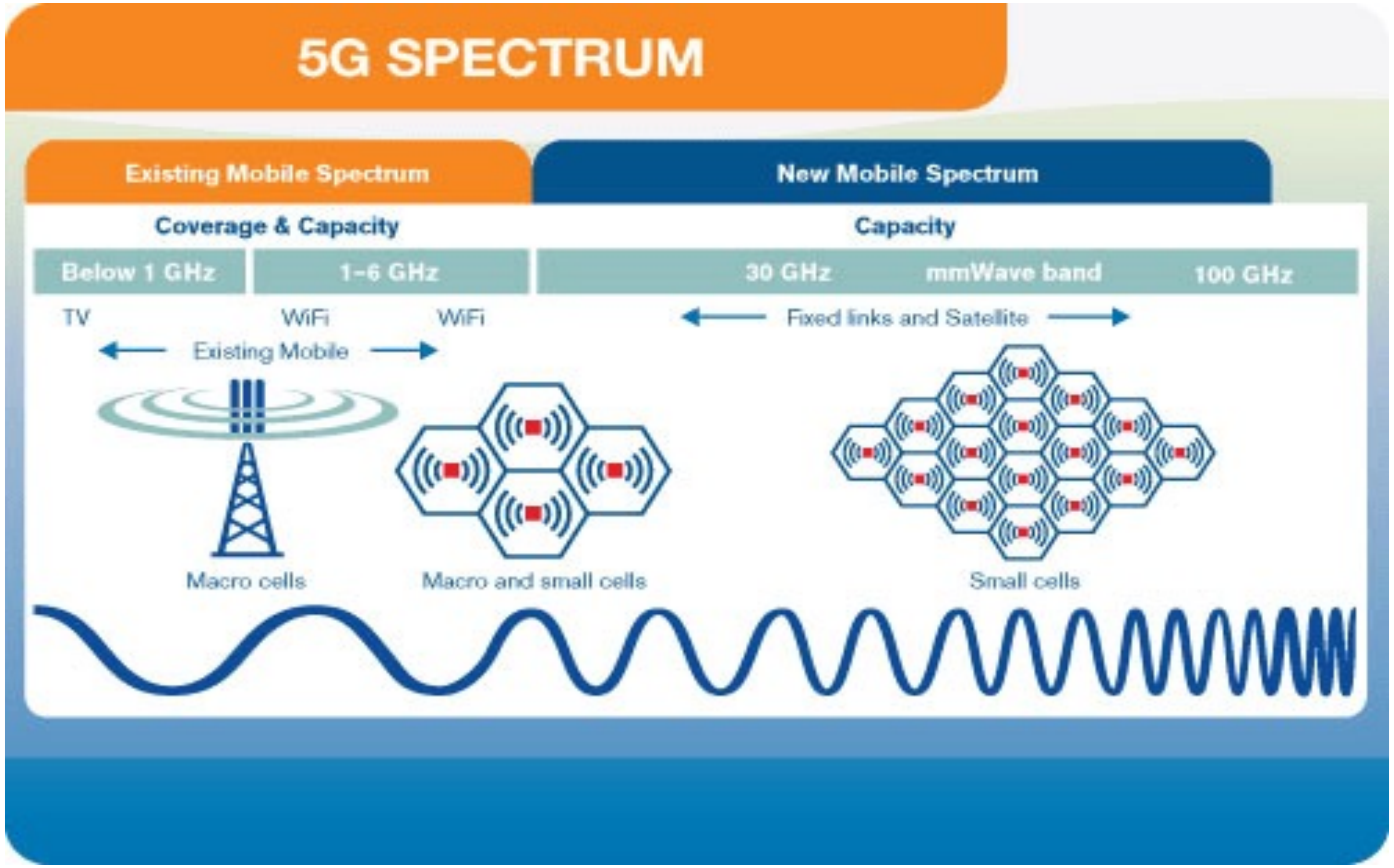


Wireless Access Link (F1)
Wireless Backhaul (F2)
Wired Connectivity
X2 Interface
Short Range Link
Core Network
Baseband Unit
Multi-Hopping
Microwave Fronthaul
Wired
Backhaul
E-band Radio
MBS
Anchor-BS
Half-Duplex
Full-Duplex
SBS



https://smallcells.3g4g.co.uk/2016/09/small-cell-forum-workshop-on-5g.html

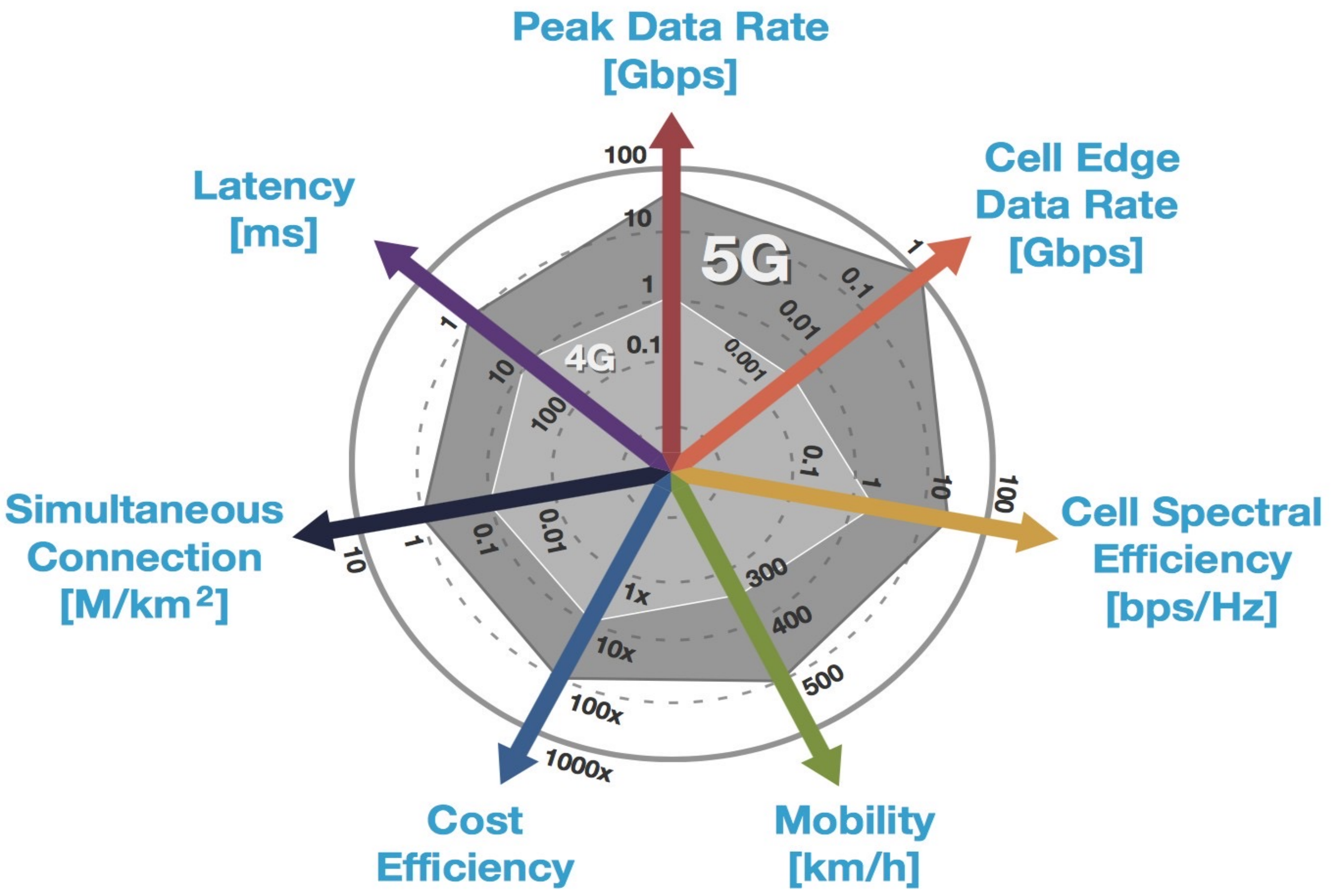
Why Millimeter wave (mmwave) ?



5G will use spectrum:

600 MHz to **6 GHz** + mmWave bands (24–86 GHz).

5G



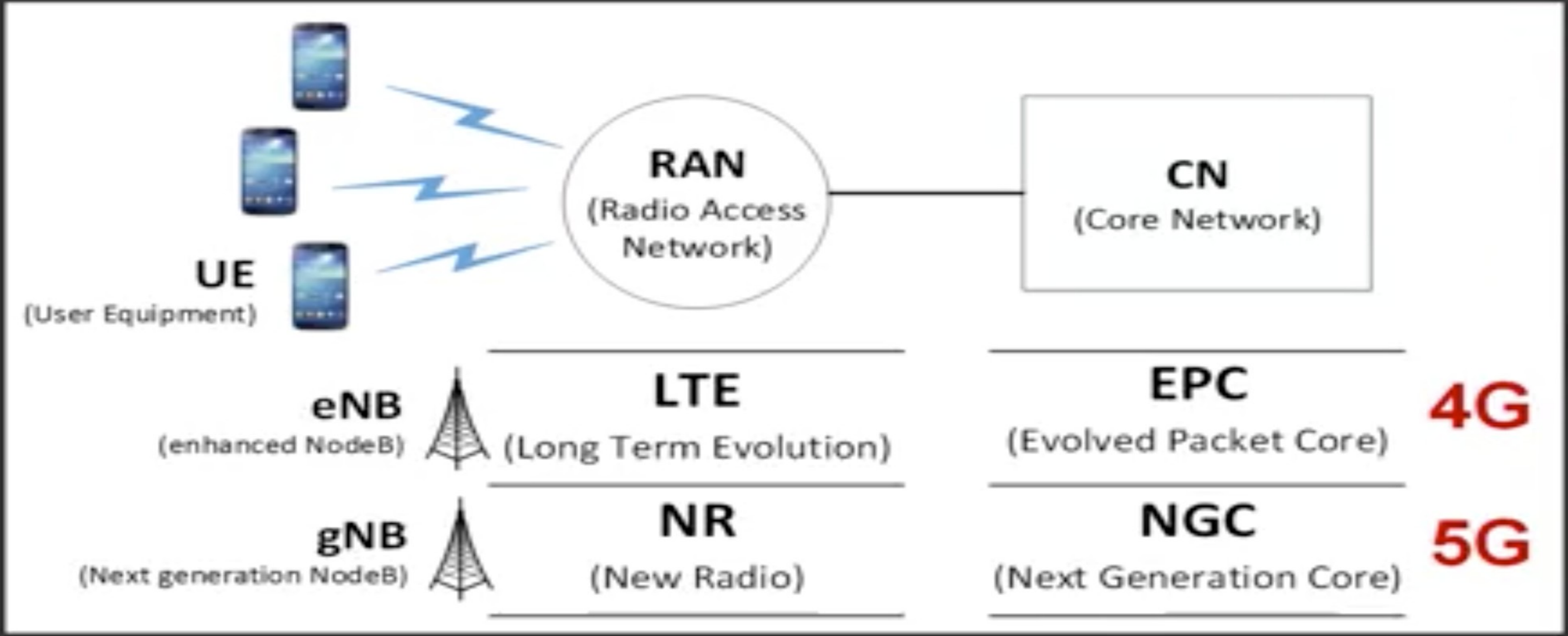
2G : digital voice, 3G : first data services, 4G : mobile broadband

5G : designed to serve not only phones but for connecting everything &

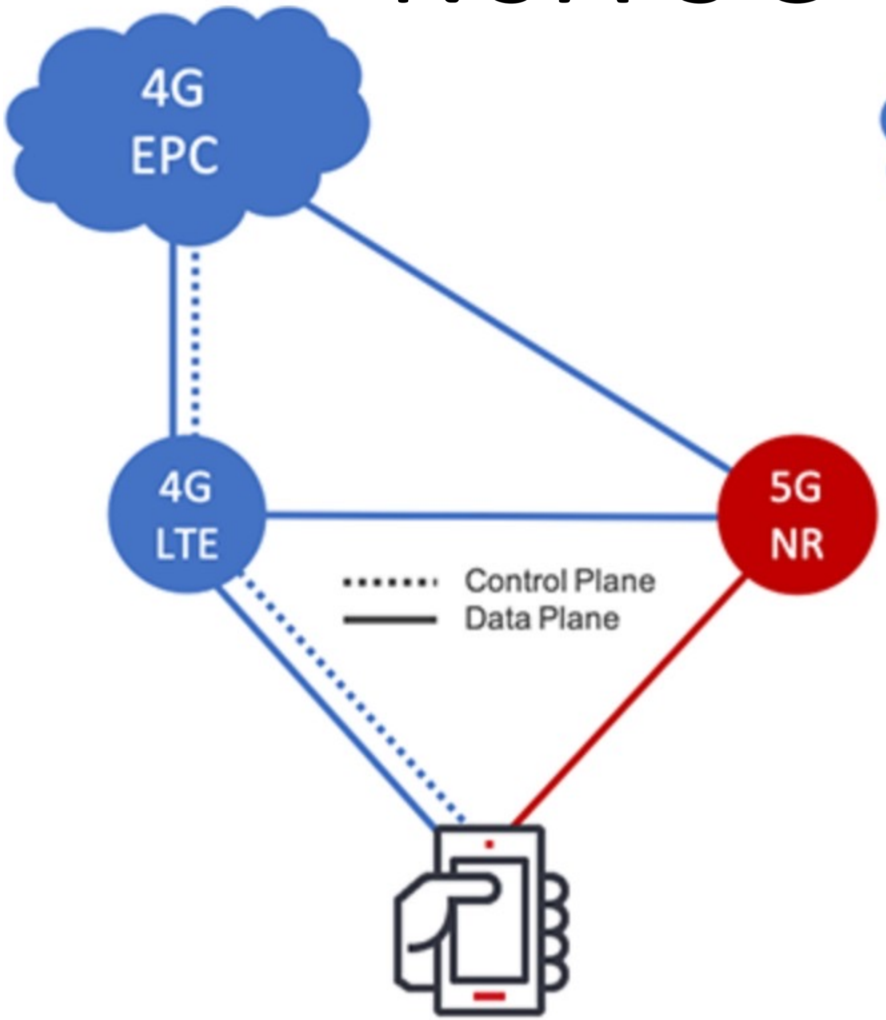
(5G Isn't About the Smartphone @ IEEE Spectrum March 2019)

5G Architecture

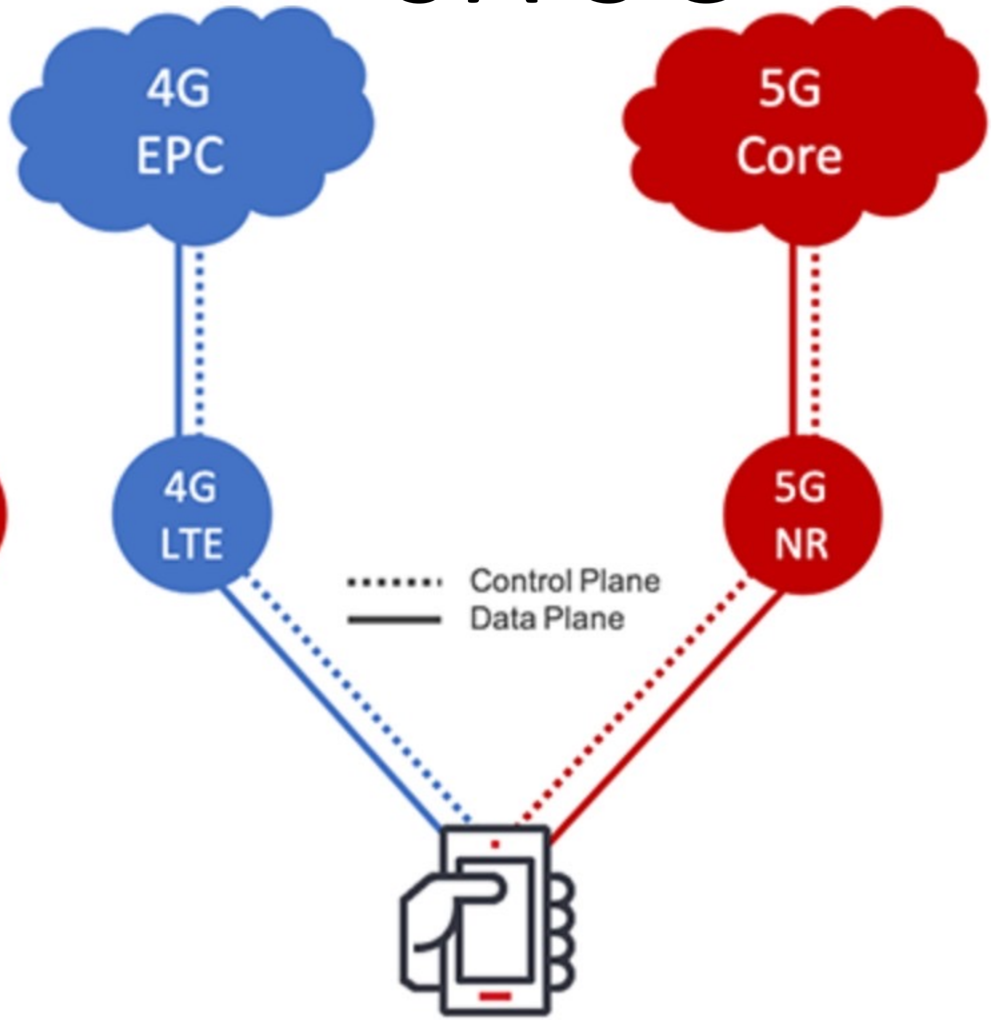
❖ Cellular Network Architecture

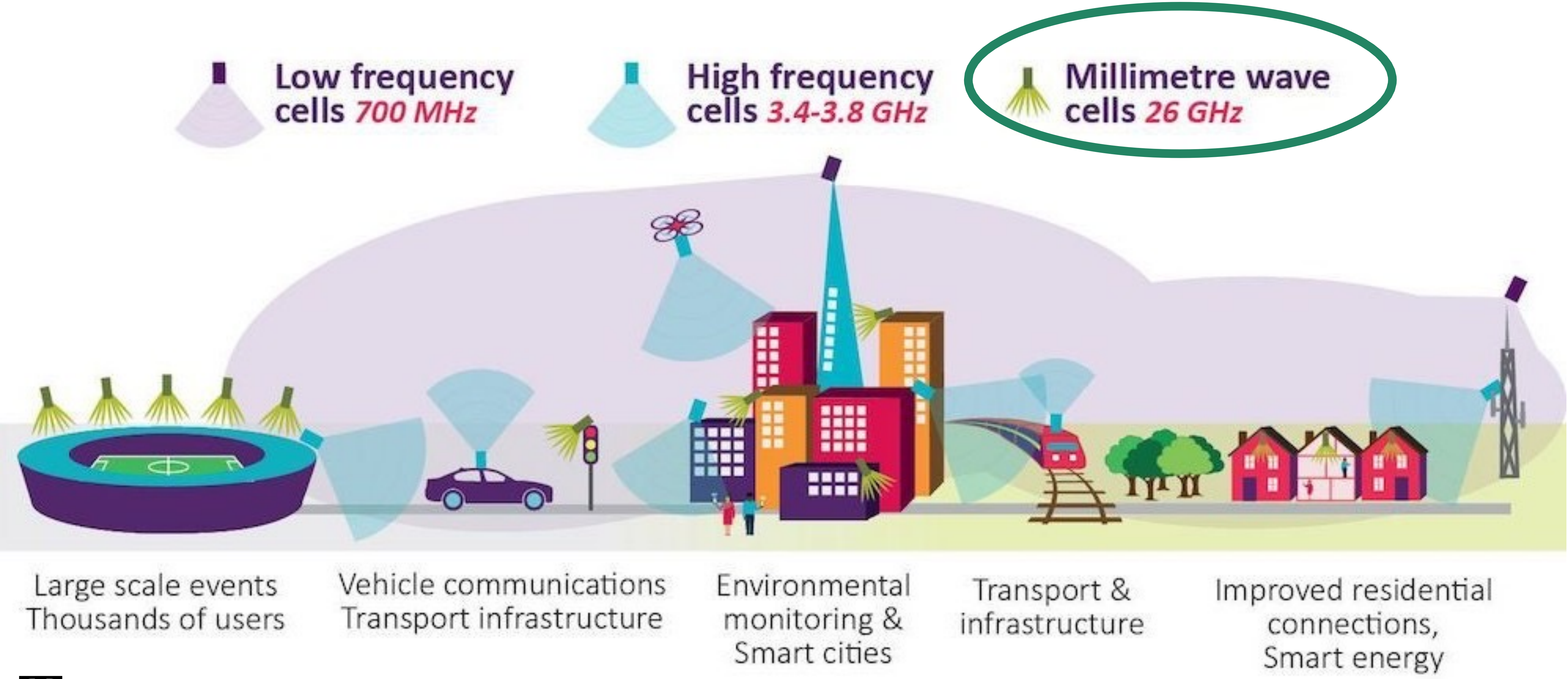


NSA 5G


4G
EPC
4G
LTE
5G
NR
Control Plane
Data Plane

SA 5G


4G
EPC
5G
Core
4G
LTE
5G
NR
Control Plane
Data Plane



THE millimeter-wave (mmWave) band : is part of the radio frequency (RF) spectrum, comprised of frequencies between 30 GHz and 300 GHz, corresponding to a wavelength range of **10 to 1 mm**. The photon energy of mmWaves ranges from 0.1 to 1.2 milli-electron volts (meV). Unlike ultraviolet, X-ray, and gamma radiation, mmWave radiation is non-ionizing, and the main safety concern is heating of the eyes and skin caused by the absorption of mmWave energy in the human body [1][2][3].

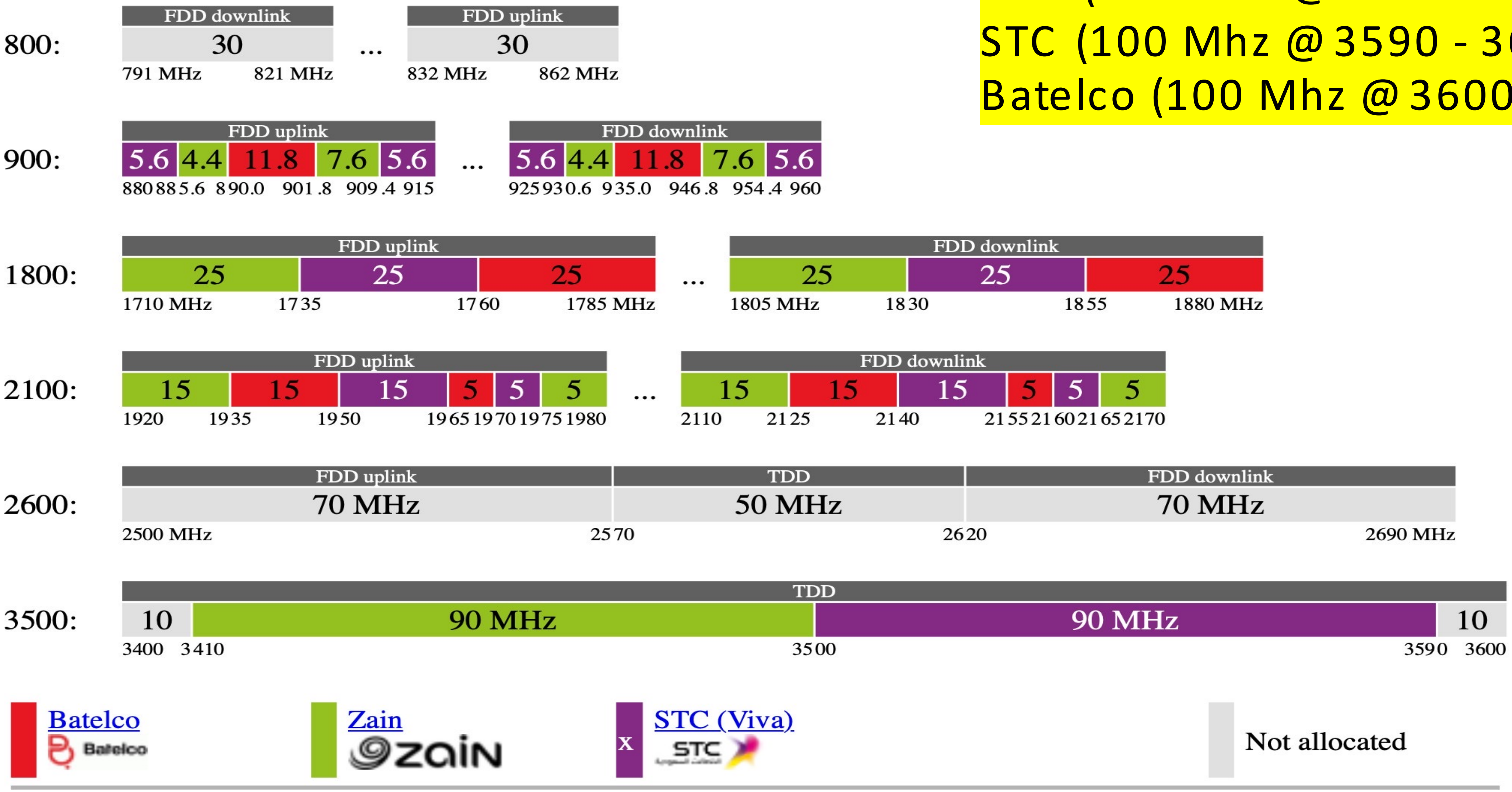
5G NR uses two frequency ranges:[4]

1. Frequency Range 1 (FR1), including **sub-6 GHz** frequency bands
2. Frequency Range 2 (FR2), including frequency bands in the mmWave range **(24–100GHz)**

Country or territory	Operator	Band									Notes
		DSS with 4G LTE	n40 2.3 GHz	n41 2.5 GHz	n78 3.5 GHz	n79 4.7 GHz	n257 28 GHz *(APAC)*	n258 26 GHz *(E* Sort ascending	n261 28 GHz	Others	
Bahrain	Batelco				90 MHz Jun 2019						[19][20][21]
	stc				90 MHz Jun 2019						[19][22][23]
	Zain				90 MHz Jun 2020						[19][24]
South Korea	LG U+				80 MHz Dec 2018		800 MHz Dec 2018				[1][175][176][177] **World's first commercial service**
	KT				100 MHz Dec 2018		800 MHz Dec 2018				[1][175][176][177] **World's first commercial service**
	SK Telecom				100 MHz Dec 2018		800 MHz Dec 2018				[1][175][176][177] **World's first commercial service**

https://www.spectrummonitoring.com/frequencies/frequencies1.html

Zain (100 Mhz @ 3400 - 3410 Band)
STC (100 Mhz @ 3590 - 3600 Band)
Batelco (100 Mhz @ 3600 - 3700 Ban



https://www.speedtest.net/ookla-5g-map

هيئة تنظيم الاتصالات
TELECOMMUNICATIONS REGULATORY AUTHORITY
Kingdom of Bahrain - مملكة البحرين

Complaints Application Forms Tenders Contact Login عربي

Consumer Stakeholders Market Information Legal Instruments Media Centre About TRA

TRA Updates

Checkout our latest news and updates about what's happening at TRA

MEDIA CENTRE → PRESS RELEASES → 5G DOWNLOAD SPEEDS IN BAHRAIN EXCEED [...]

5G Download Speeds in Bahrain Exceed 1 GB – according to TRA's latest Quality of Service Measurement Report

April 21,2020

The Telecommunications Regulatory Authority of Bahrain announced the publication of their latest Quality of Service Report, shedding light on the progress of 5G Networks.

A comparison between 4G and 5G performance shows average speeds of approximately 80 megabits per second compared to 5G's average of approximately 600 megabits per second, though records higher than 1 GB per second were observed.

Recent News

April 21,2020
5G Download Speeds in Bahrain Exceed 1 GB – according to TRA's latest Quality of Service ...

April 01,2020
89% increase in disputes, TRA continues efforts in protection of telecoms service consumers: ...

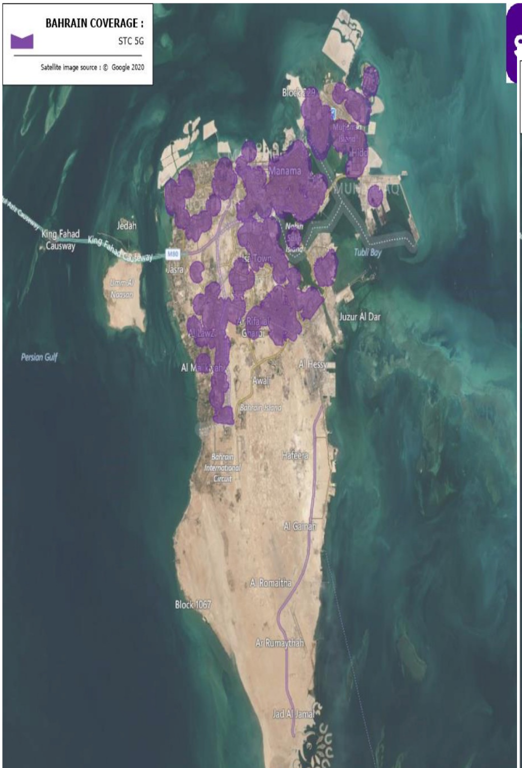
March 23,2020
TRA supports national initiatives in combating COVID-19

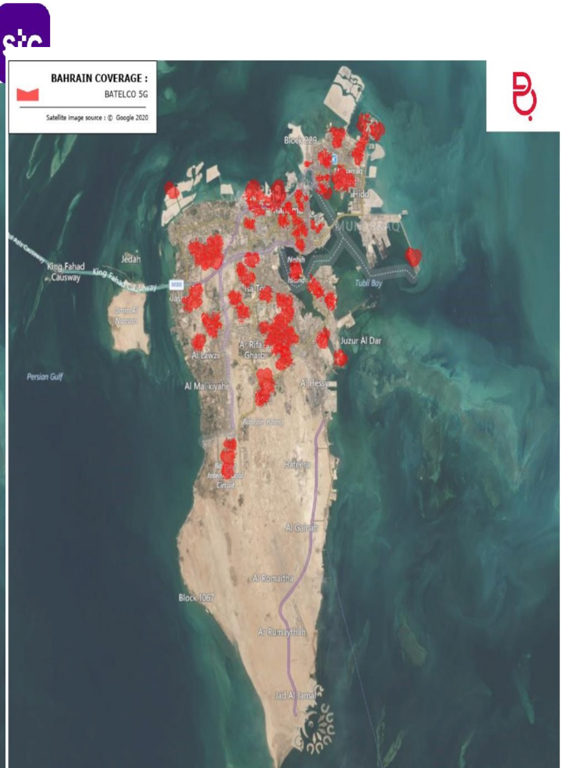
February 22,2020
TRA opens registration for Cyber Safety Award

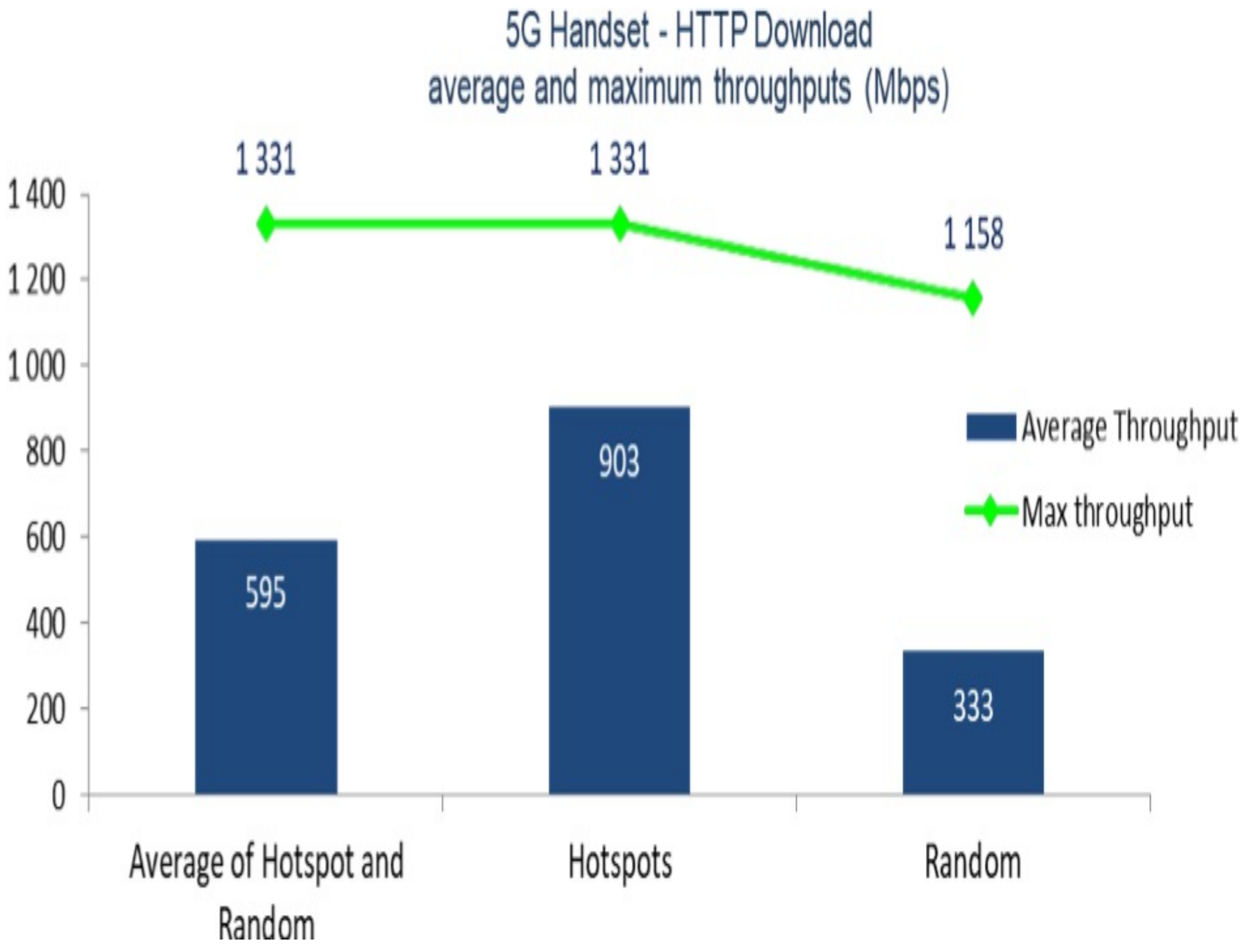
5G NETWORKS

QOS AND COVERAGE AUDIT KINGDOM OF BAHRAIN

4G = approximately 80 megabits per second. compared to 5G's average of approximately 600 megabits per second, though records higher than 1 GB per second were observed.







5G Map Sites

Location	Block #					
Adliya	336	338				
Hoora	308	701	815			
Bab Al-Bahrain	301	304				
Karababad	436					
Manama	301	302	304	311	314	
	316	317	319	326	328	346
Juffair	324	340				
Sitra	604	607	615			
Sanad	743	816				
Reef Island	346					

K.H. Hospital	228		
Ma'ameer	607	615	634
Sanabis	408		
Seef	428	436	

Zubara Road	318
Nabeeh Saleh	381
Mahooz	337
Ras Roman	318

http://content.batelco.com/wp-content/uploads/2019/09/16085231/batelco-5g-Maps.pdf

5G devices

5G

5G Non-Standalone (NSA), Standalone (SA), Sub6 / mmWave

[redacted]

first commercial 5G smartphone HUAWEI Mate 20 X (5G) is launched globally.[2]

On March 19, HMD Global, the current maker of Nokia-branded phones, announced the Nokia 8.3, support all 5G bands from 600 MHz to 3.8 GHz.[62]

At the time of writing (July **2020**), no **iPhone** models **support 5G**.

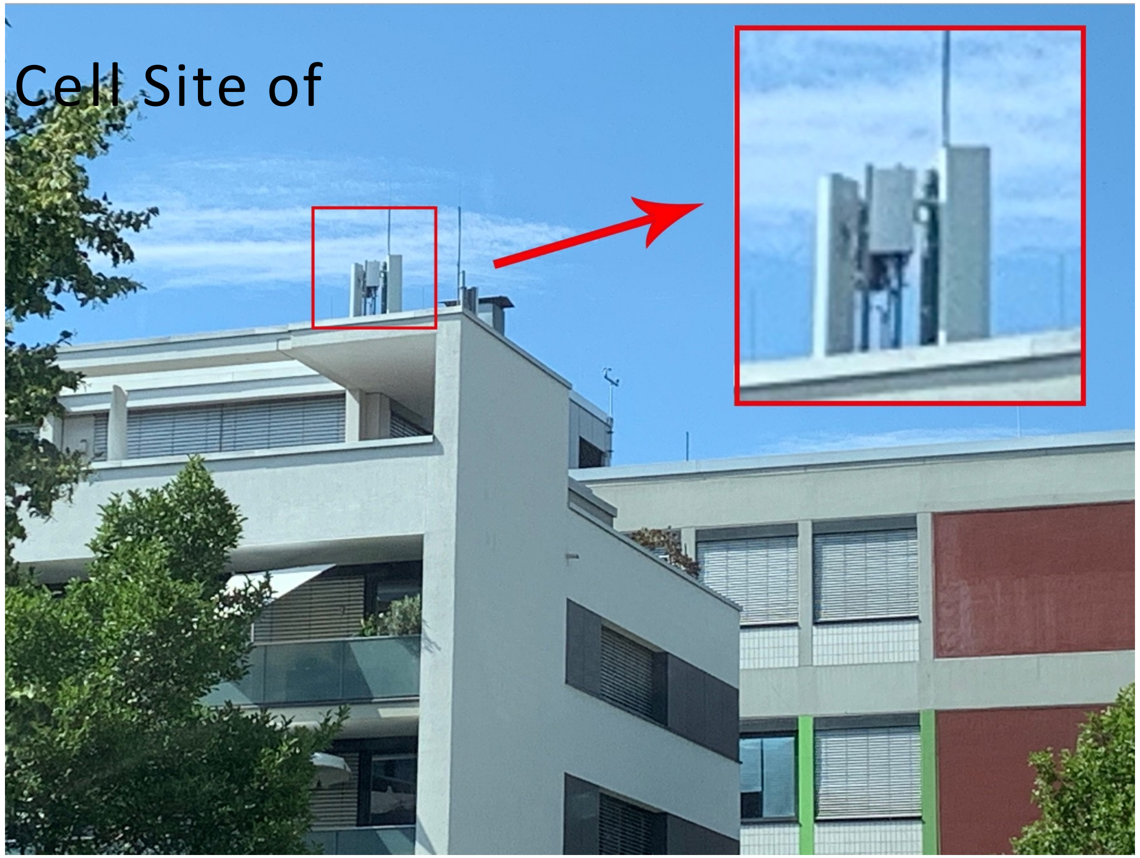
Will the iPhone 12 be Apple's first 5G phone?

5G vs 4G cells

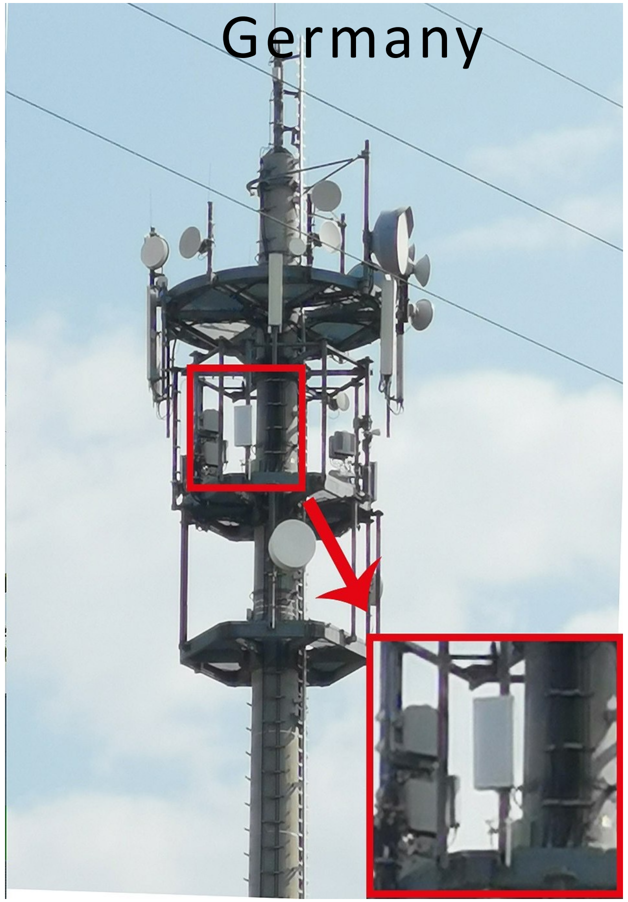
https://vividcomm.com/2019/10/04/5g-small-cells/

5G 3.5 GHz Cell Site of Deutsche Telekom in Darmstadt, Germany

5G 3.5 GHz Cell Site of



Vodafone in Karlsruhe, Germany



5G NR (New Radio) is a new radio access technology (RAT) developed by **3GPP** for the **5G** (fifth generation) mobile network. It was designed to be the global standard for the air interface of **5G** networks. ... **gNB** (i.e. a 5G next generation base station),

NSA Vs. SA options

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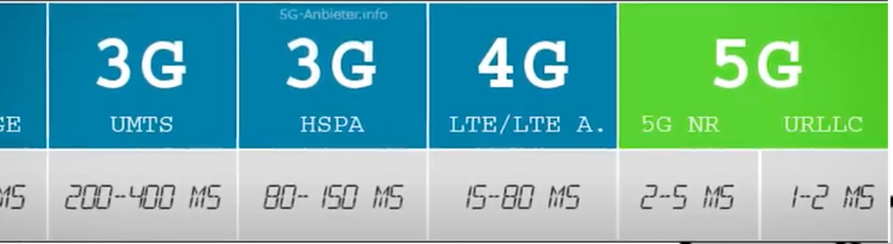
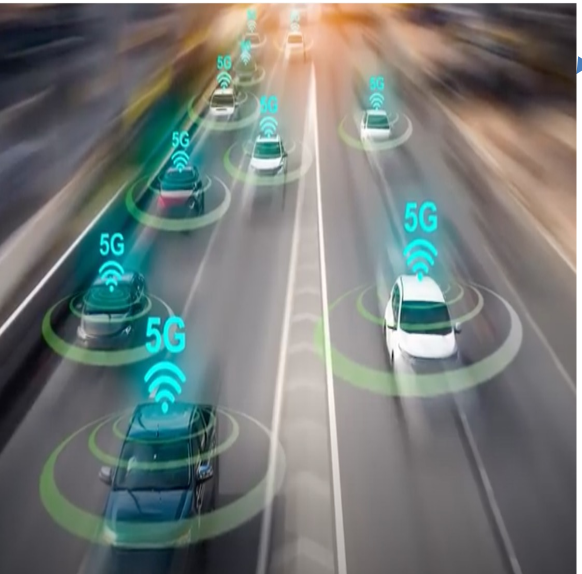


4G vs 5G

Performance Metrics	4G	5G
Peak data rate (Gbps)	1	20
User experienced data rate (Mbps)	10	100
Connection density (devices/km^2)	10^5	10^6 (IOT)
Mobility support (kmph)	350	500
Area traffic capacity (Mbit/s/m^2)	0.1	10
Latency (ms)	10	1
Reliability (%)	99	99.99
Positioning accuracy (m)	1	0.01
Spectral efficiency (bps/Hz)	3	10
Network energy efficiency (J/bit)[1]	1	0.01



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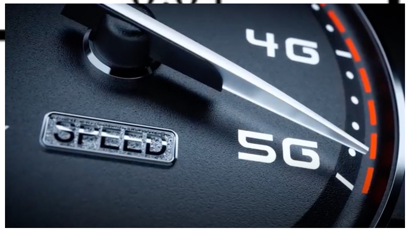
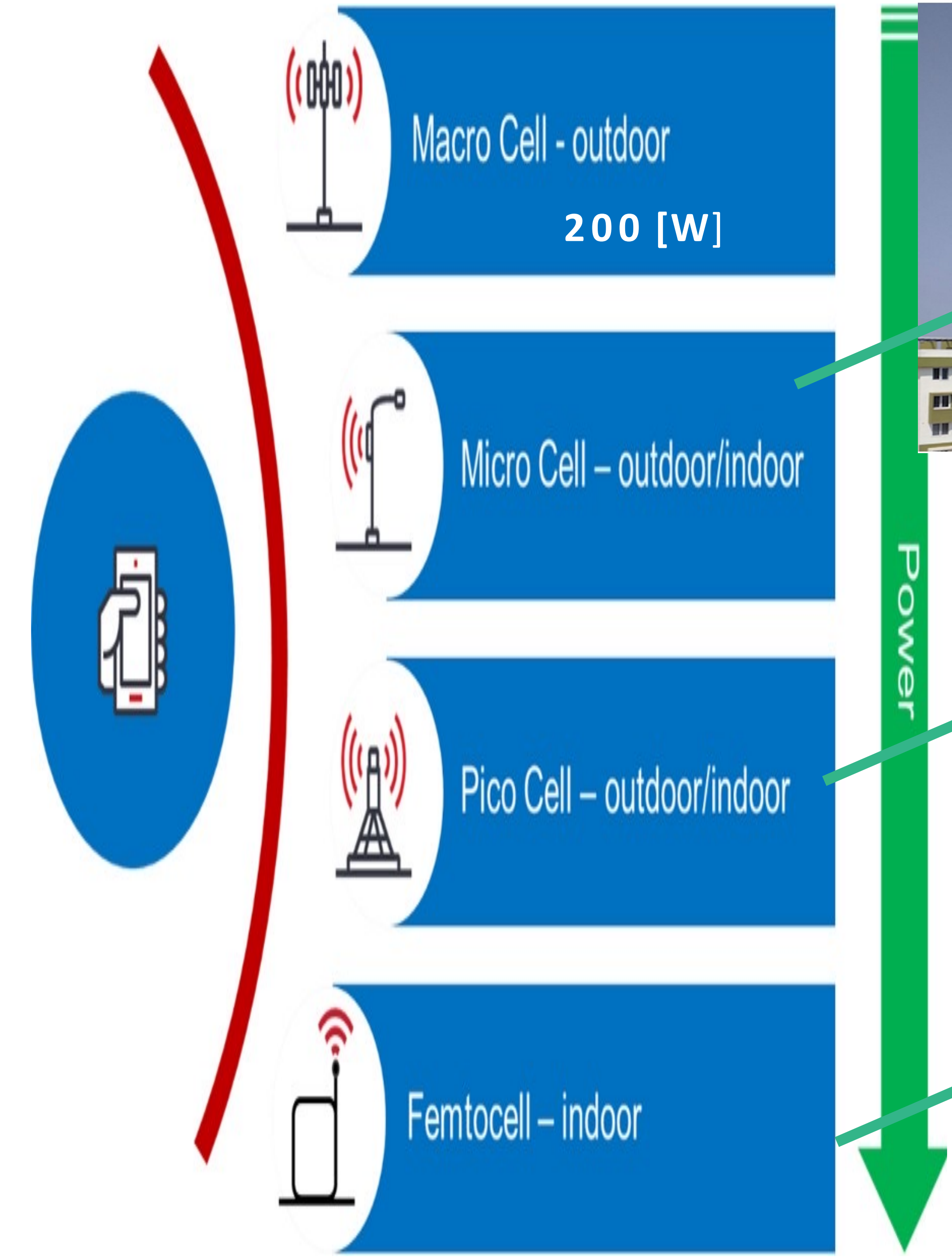
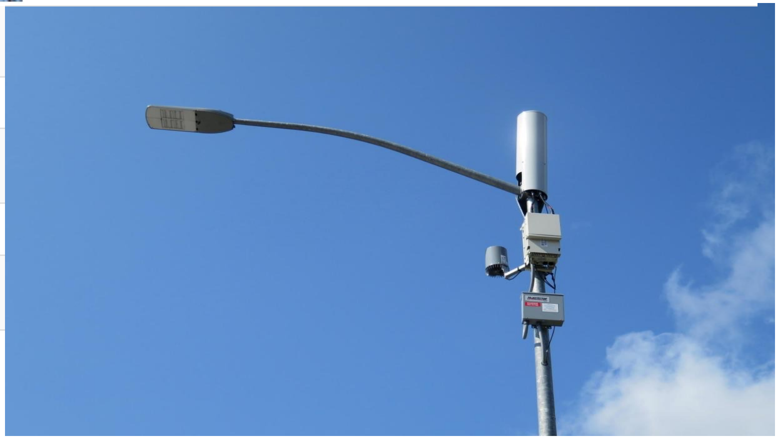




Coverage area	500 meters to 2.5 kilometers
Power	2 to 5 watts
Number of users	up to 200 simultaneous users
Backhaul	Wired, fiber connection and microwave links
Application	Outdoor applications
Cost	Medium cost

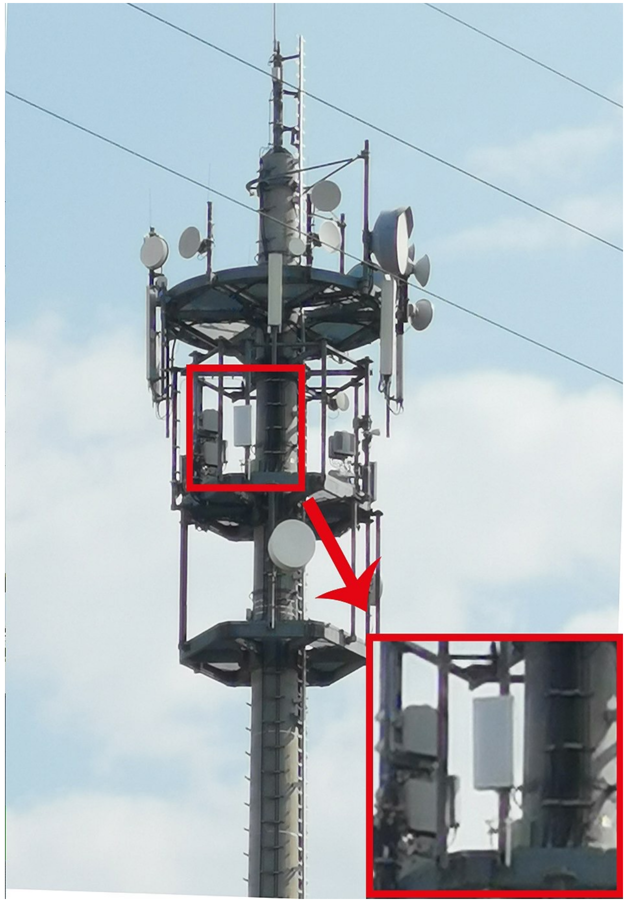
Coverage area	100 meters to 250 meters (indoors)
Power	Typically 250 milliwatts
Number of users	32 to 64 users
Backhaul	Wired, fiber connection
Application	Indoor applications (offices, hospitals, shopping centre and schools)
Cost	Low cost



Coverage area	10 meters to 50 meters (indoors)
Power	Typically 100 milliwatts
Number of users	8 to 16 users
Backhaul	Wired, fiber connection
Application	Indoor (primarily for indoor application, can be used for outdoor applications)
Cost	Low cost

5G 3.5 GHz Cell Site of Deutsche Telekom in Darmstadt, Germany

5G 3.5 GHz Cell Site of Vodafone in Karlsruhe, Germany



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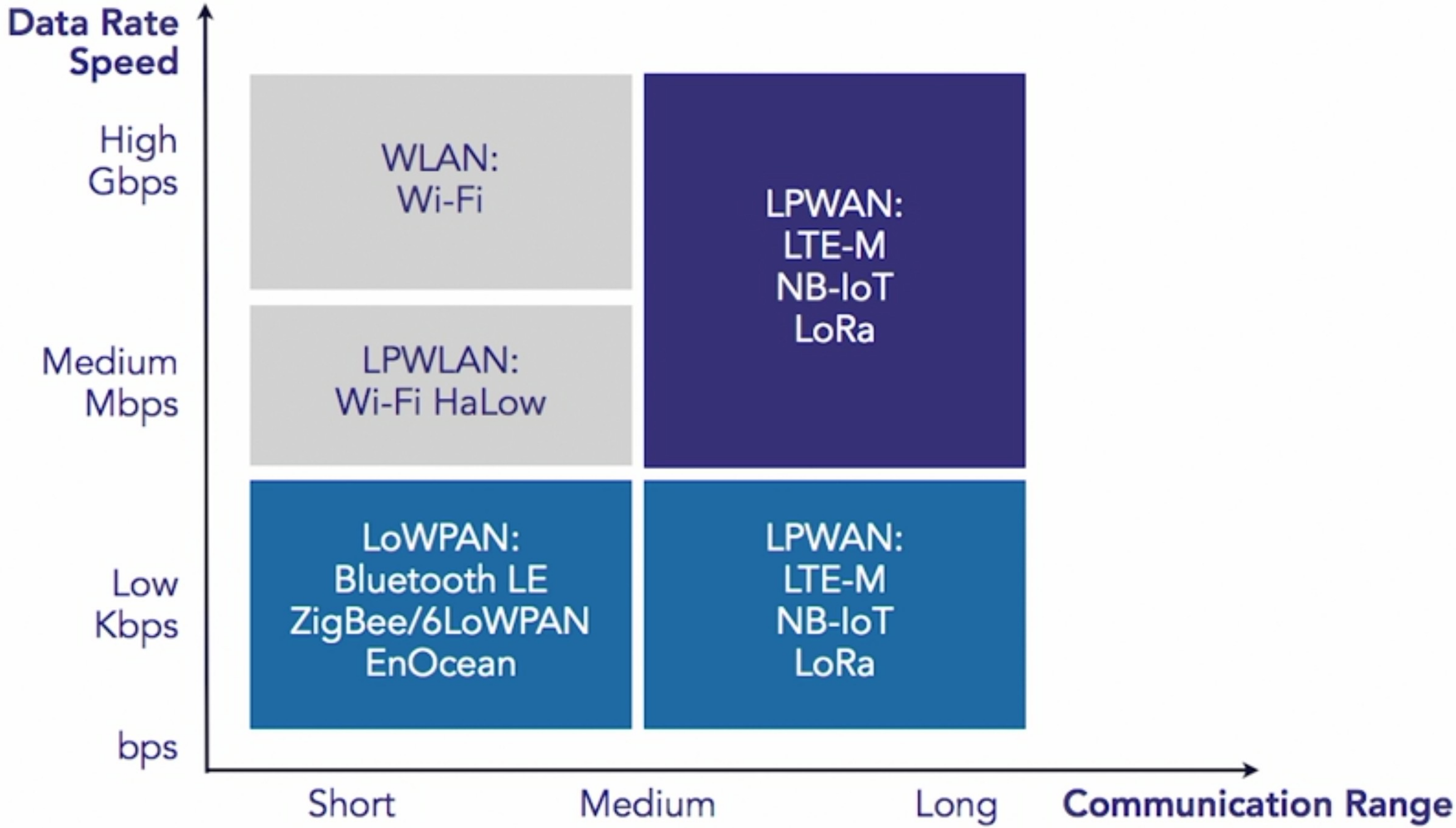
IoT wireless technologies comparisons

	NB-IoT NB-IoT	WIFI	BLUETOOTH	SIGFOX	LoRa	LTE-M/ (eMTC) (Rel 13) eMTC	EC-GSM (Rel. 13)	ZIGBEE Pro	5G (targets)
Coverage Area	<15 km 164 dB	17-30+ (meters)	1-10+ (meters)	<12km 160 dB	<10 km 157 dB	<10 km 156 dB	<15 km 164 dB	1-100+ (meters)	**<12km 160 dB**
Spectrum Bandwidth	Licensed 7-900MHz 200 kHz shared	2.4 GHz 802.11	2.4 GHz 802.15.1	Unlicensed 900MHz 100kHz	Unlicensed 900MHz <500kHz	Licensed 700MHz-900MHz 1.4 MHz shared	Licensed 800MHz-900MHz shared	2.4G 802.15.4	Licensed 700MHz-900MHz shared
Rate	<50 kbps	150Mbps	1Mbps	<100bps	<10 kbps	<1 Mbps	10 kbps	250kbps	<1 Mbps
Terminal cost	4.00$ (2015) 2-3$ (2020)	4.00$ (2016)	4.00$ (2016)	4.00$ (2015) 2.64$ (2020)	4.00$ (2015) 2.64$ (2020)	5.00$ (2015) 3.30$ (2020)	4.5$ (2015) 2.97$ (2020)	3.00$ (2016)	<2$
Network Reforming	Small to moderate	None	None	Large	Large	Small	Moderate (LTE reuse)	None	Requires 5G NWs

FIGURE 2. **Performance Comparison of some common IoT Technologies [3], [23] and [17].**



Data Rate Speed
High Gbps
Medium Mbps
Low Kbps
bps
WLAN:
Wi-Fi
LPWLAN:
Wi-Fi HaLow
LPWAN:
LTE-M
NB-IoT
LoRa
LoWPAN:
Bluetooth LE
ZigBee/6LoWPAN
EnOcean
LPWAN:
LTE-M
NB-IoT
LoRa
Short
Medium
Long
Communication Range

Table 1.2 Overview of communication technologies and standards for IoT.

Name	Frequency	Range	Examples	Standards
Bluetooth BLE	2.4 GHz	1–100 m >100 m	Headsets, wearables, sports and fitness, health care, proximity, automotive	IEEE 802.15.1[a)] Bluetooth SIG [b)]
EnOcean	315 MHz, 868 MHz, 902 MHz	300 m outdoor, 30 m indoors	Monitoring and control systems, building automation, transportation, logistics	ISO/IEC 14543-3-10[c)]
GSM, LTE, LTE-M	Europe: 900 MHz and 1.8 GHz, USA: 1.9 GHz and 850 MHz		Mobile phones, asset tracking, smart meters, M2M	3GPP[d)]
6LoWPAN	2.4 GHz	10–30 m	Automation and entertainment applications in home, office, and factory environments	Adaption layer for Ipv6 over IEEE802.15.4[e)]
LoRa	Sub 1 GHz ISM band	2–5 km urban; 15 km suburban; 45 km rural	Smart city, long-range M2M	LoRaWAN[f)]
NB-IoT (narrow-band-IoT)	700–900 MHz	10–15 km rural deep indoor penetration	Smart meters, event detectors, smart cities, smart homes, industrial monitoring	3GPP LTE Release 13[g)]
NFC	13.56 MHz	Under 0.2 m	Smart wallets, smart cards, action tags, access control	ISO/IEC 18092[h)] ISO/IEC 14443-2,-3,-4[i)]
NWave	Sub 1 GHz ISM band	Up to 10 km	Agriculture, smart cities, smart meters, logistics, environmental	Weightless[j)]
RFID	120–150 kHz (LF), 13.56 MHz (HF), 2450–5800 MHz (microwave), 3.1–10 GHz (microwave)	10 cm to 200 m	Road tolls, building access, inventory, goods tracking	ISO 18000[k)]

DASH7	433 MHz (UHF), 865–868 MHz (Europe), 902–928 MHz (North America) UHF	0–5 km	Building automation, smart energy, smart city logistics	
SigFox[l)]	900 MHz	3–10 km urban 30–50 km rural	Smart meters, remote monitoring, security	
Weightless	470–790 MHz	Up to 10 km	Smart meters, traffic sensors, industrial monitoring	Weightless[m)]
Wi-Fi	2.4 GHz, 3.6 GHz, 4.9–5 GHz	Up to 100 m	Routers, tablets, smartphones, laptops	IEEE 802.11[n)]
Z-Wave	ISM band 865–926 MHz	100 m	Monitoring and control for homes and light commercial environments	Z-Wave[o)]; recommendation ITU G.9959[p)]
ZigBee	2.4 GHz; 784 MHz in China, 868 MHz in Europe, and 915 MHz in USA and Australia	10–20 m	Home and building automation, WSN, industrial control	IEEE 802.15.4[q)]