Communications Options for Wireless Sensor Networks

Marco Zennaro, ICTP
Sebastian Büttrich, NSRC

last edit: Dec 2014, AIT, Bangkok

NSRC
Network Startup Resource Center

WSN communications options

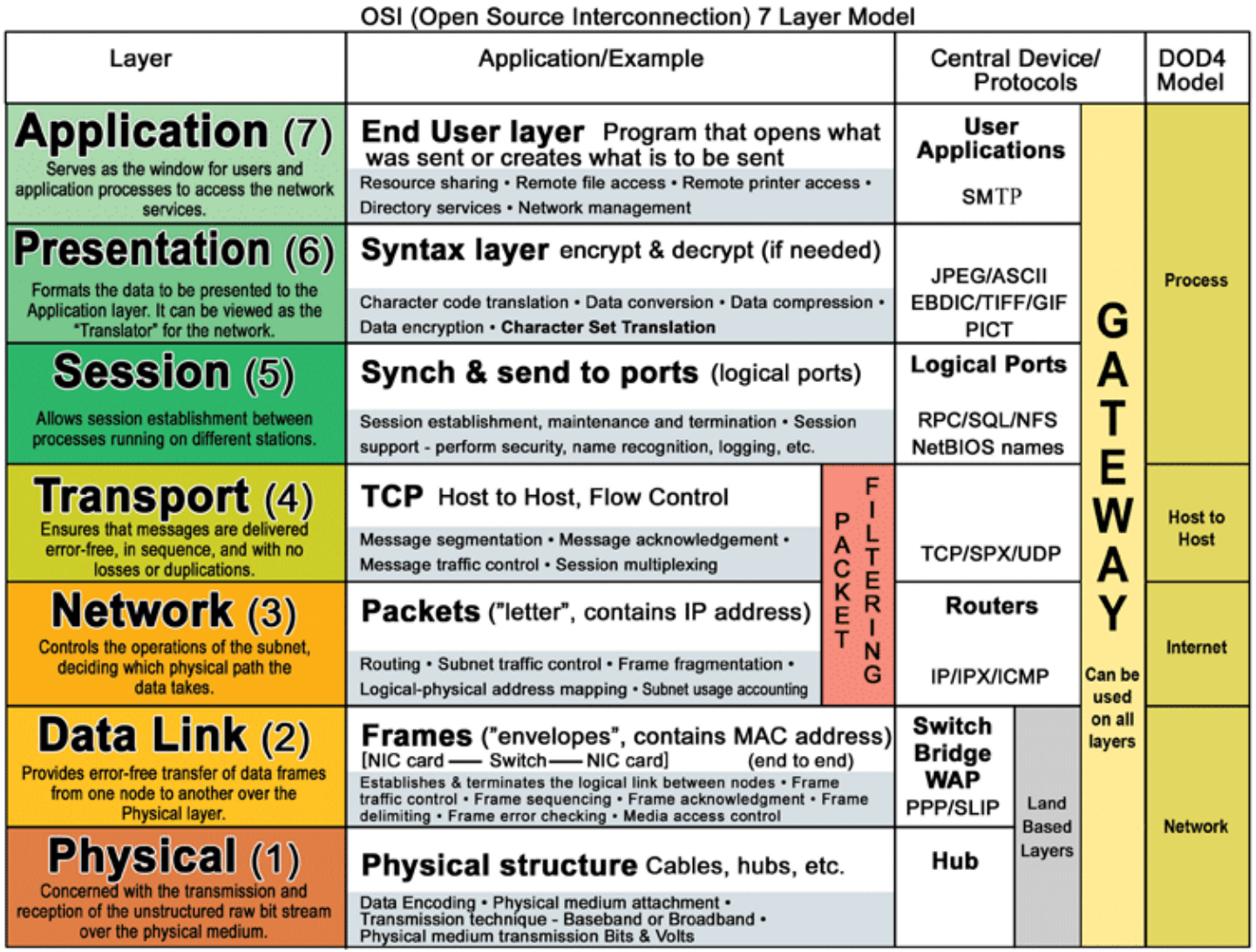
When considering communications options, our criteria come from a variety of areas:

Physical layer
Network layer

Regulative layer
Economical layer

Human/Social/Political layer

Layer models



Physical & Network layer

Physical layer
- Frequency
- Range
- Power requirements

(consider: wired options?)

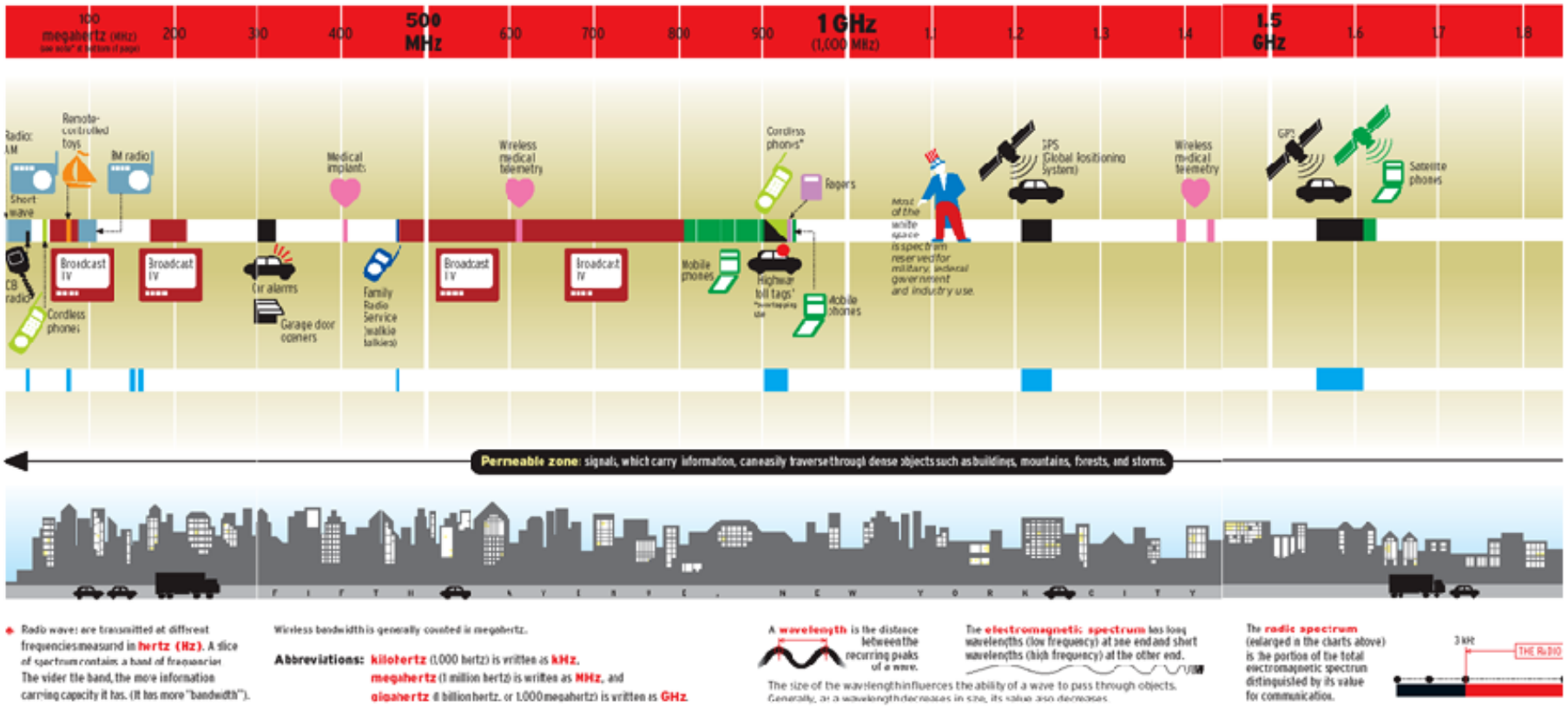
Network layer
- Data rate
- Topology (Star, mesh, ..)

Frequency: some simple rules

- The lower the frequency,
  the further it goes
- The lower the frequency, the better it goes through and around things
- The higher the frequency,
  the more data it can transport

WSN usually (!) require low data rate, long range ==>
low frequencies (e.g. 433 MHz, 868/900 MHz)

Electromagnetic Spectrum



◆ Radio waves are transmitted at different frequencies measured in **hertz (Hz)**. A slice of spectrum contains a band of frequencies. The wider the band, the more information carrying capacity it has. (It has more "bandwidth").

Wireless bandwidth is generally counted in megahertz.

Abbreviations: **kilohertz** (1,000 hertz) is written as **kHz**, **megahertz** (1 million hertz) is written as **MHz**, and **gigahertz** (1 billion hertz, or 1,000 megahertz) is written as **GHz**.

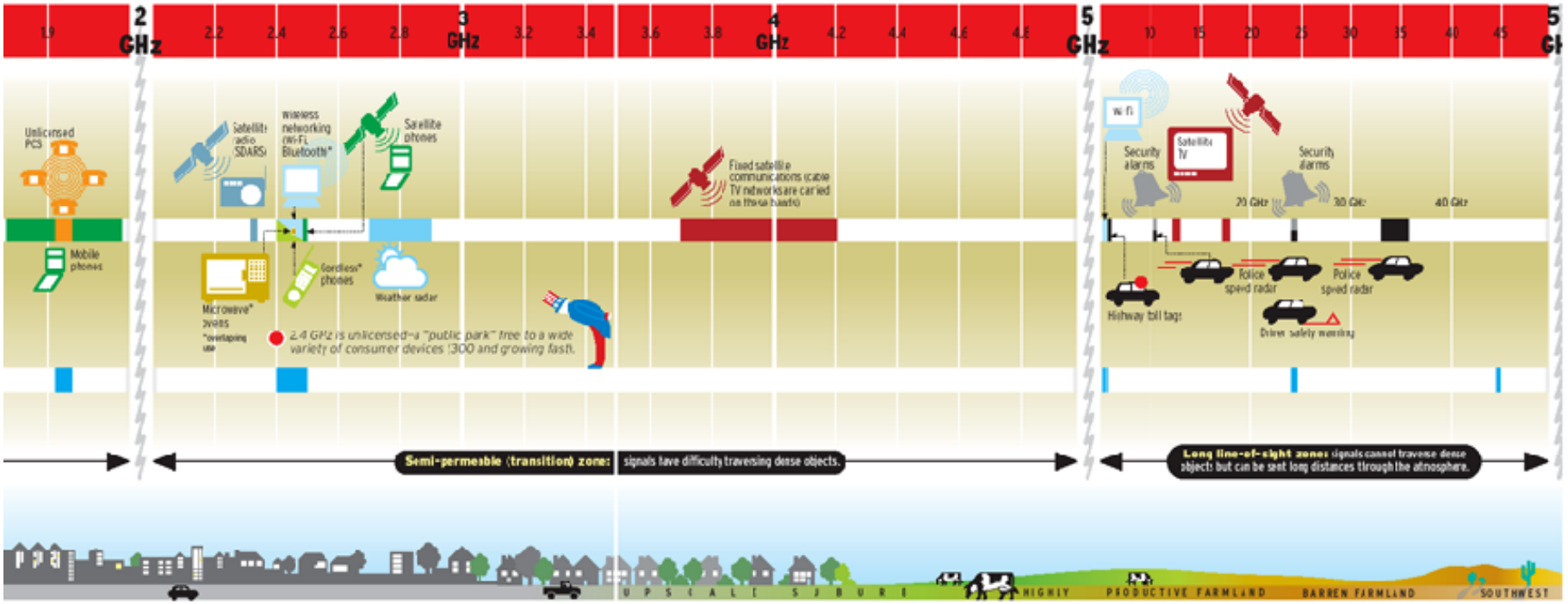
A **wavelength** is the distance between the recurring peaks of a wave.

The **electromagnetic spectrum** has long wavelengths (low frequency) at one end and short wavelengths (high frequency) at the other end.

The size of the wavelength influences the ability of a wave to pass through objects. Generally, as a wavelength decreases in size, its value also decreases.

The **radio spectrum** (enlarged in the charts above) is the portion of the total electromagnetic spectrum distinguished by its value for communication.

Electromagnetic Spectrum



The amount of spectrum required for everyday communications

Today, most wireless communication is low fidelity audio. In the future, high fidelity video could require up to 5,000 times as much bandwidth.

"The basic problem is that demand for spectrum is outstripping the supply."
U.S. General Accounting Office Report, September 2002

WSN communications options

There are the following options for WSN communications:

1. 802.15.4 (WPAN)
   Zigbee
   WiFi (low power …)
   Bluetooth (BTLE low energy)
   GSM
   Satellite
   TV White Spaces
   (Wired)

802.15.4 – Layer 2 IEEE Standard

802.11 – Wireless Local Area Networks (WiFi)

802.11a, 802.11b, 80211g, 802.11n

802.15 – Wireless Personal Access Networks (WPAN)

Task Group 1 – Bluetooth (802.15.1)

Task Group 2 – Co-existence (802.15.2)

Task Group 3 – High Rate WPAN (802.15.3)

Task Group 4 – Low Rate WPAN (802.15.4 or 802.15 TG4)

Task Group 5 – Mesh Networking (802.15.5)

802.16 – Wireless Metropolitan Area Networks (WiMax)

802.20 – Mobile Broadband Wireless Access (Mobile-Fi) - Defunct

802.22 – Wireless Regional Access Network (WRAN)

Utilise free space in the allocated TV spectrum

802.15.4 - physical layer

Channels:

- 868.0 - 868.6MHz -> 1 channel (Europe)
- 902.0-928.0MHz -> 10 channels (US)
- 2.40-2.48GHz -> 16 channels (Worldwide)

Bit Rates:

- 868.0 - 868.6MHz -> 20/100/250 Kb/s
- 902.0-928.0MHz -> 40/250 Kb/s
- 2.40-2.48GHz -> 250 Kb/s

802.15.4 - node types

Full-function device (FFD).

It can serve as the coordinator of a personal area network just as it may function as a common node. It implements a general model of communication which allows it to talk to any other device: it may also relay messages, in which case it is dubbed a coordinator.

Reduced-function devices (RFD).

These are meant to be extremely simple devices with very modest resource and communication requirements; due to this, they can only communicate with FFDs and can never act as coordinators.

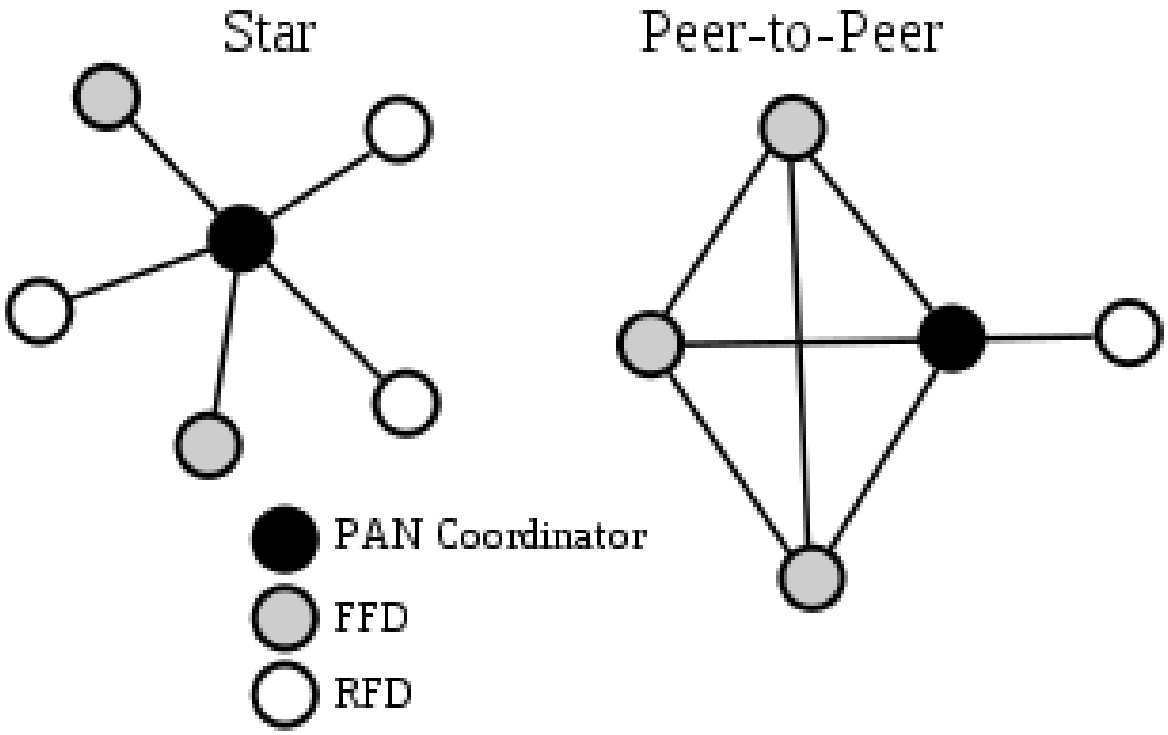
802.15.4 - topologies

Networks can be built as either **peer-to-peer** or **star** networks.

However, every network needs **at least one FFD to work as the coordinator of the network**.

Each device has a unique 64-bit identifier, and if some conditions are met short 16-bit identifiers can be used within a restricted environment. Namely, within each PAN domain, communications will probably use short identifiers.

802.15.4 - topologies



Max number of devices is 65535.

802.15.4 - characteristics

1.	Range	10m
2.	Multihop capabilities	no
3.	Battery consumption	low
4.	Security	no
5.	Cost (device)	low
	Cost (service)	free
	Availability	good
	Regulation	good

Zigbee

This standard defines a communication layer at **level 3** and upper in the OSI model. Its main purpose is to create a network topology (hierarchy) to let a number of devices communicate among them and to set extra communication features such as authentication, encryption, association and in the upper layer application services.

It was created by a set of companies which form the ZigBee Alliance.

Zigbee

ZigBee offers basically four kinds of different services:

Encryption services (application and network keys implement extra 128b AES encryption)

Association and authentication (only valid nodes can join to the network).

Zigbee

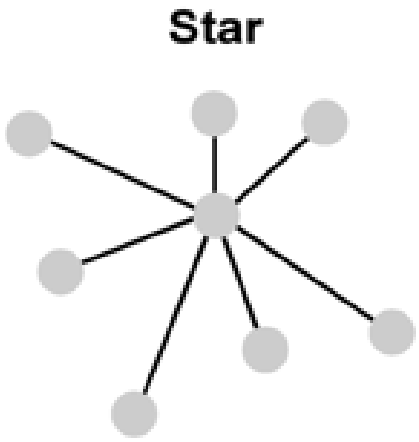
Routing protocol: AODV (Ad hoc On-Demand Distance Vector Routing), a reactive ad hoc protocol has been implemented to perform the data routing and forwarding process to any node in the network.

Application Services: An abstract concept called "cluster" is introduced. Each node belongs to a predefined cluster and can take a predefined number of actions. Eg: the "house light system cluster" can perform two actions: "turn the lights on", and "turn the lights off".

Zigbee - topology

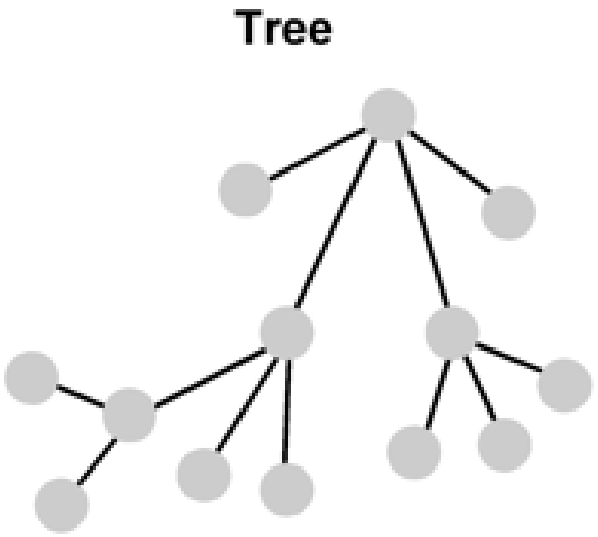
A ZigBee network can adopt one of the three topologies: Star, Tree, Mesh.

Star Topology: a Star network has a central node, which is linked to all other nodes in the network. All messages travel via the central node.



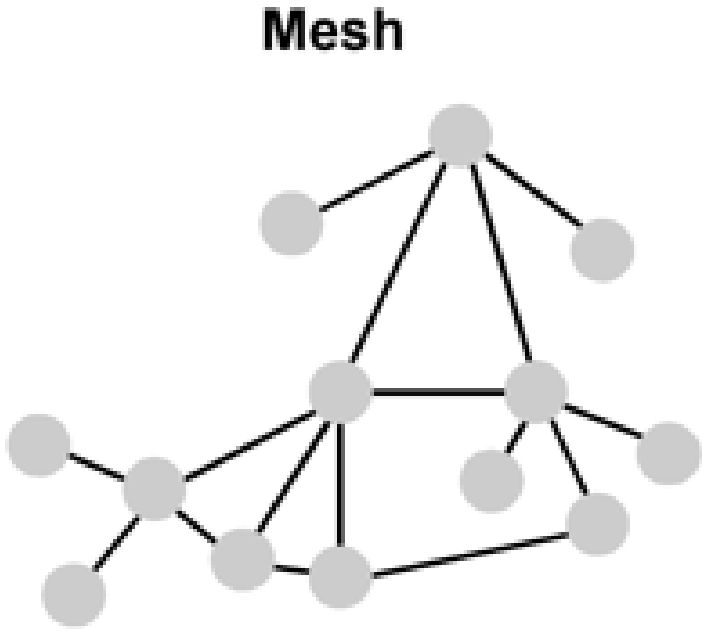
Zigbee - topology

Tree Topology: a Tree network has a top node with a branch/leaf structure below. To reach its destination, a message travels up the tree (as far as necessary) and then down the tree.



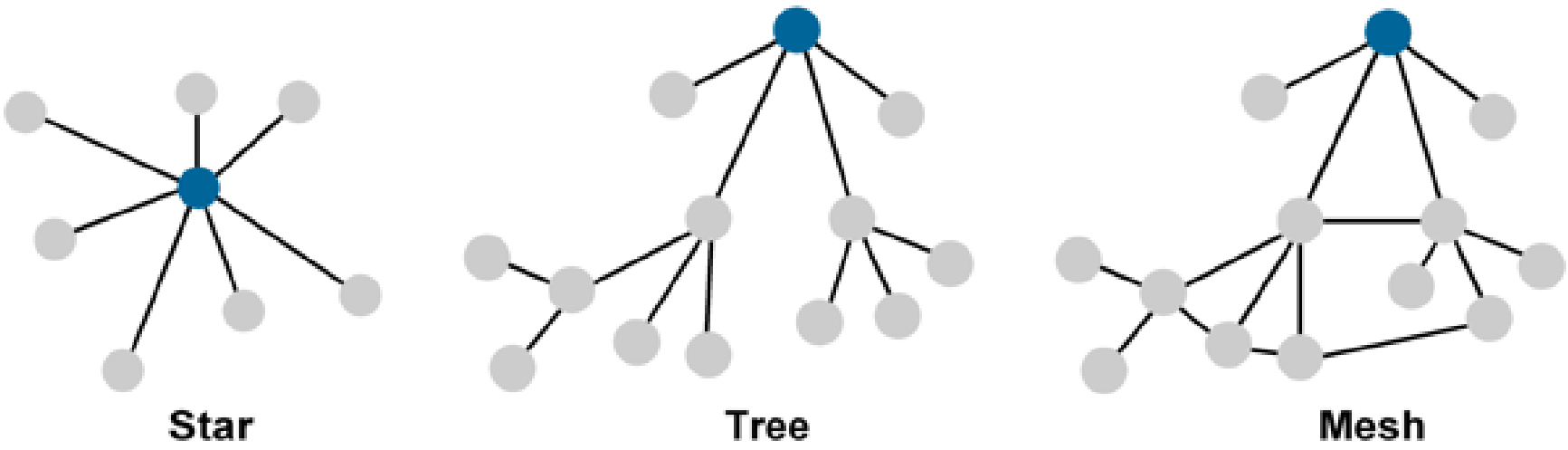
Zigbee - topology

Mesh Topology: a Mesh network has a tree-like structure in which some leaves are directly linked. Messages can travel across the tree, when a suitable route is available.



Zigbee - node types

Co-ordinator: all ZigBee networks must have one (and only one) Co-ordinator



Zigbee - node types

The tasks of the **Co-ordinator** at the network layer are:

- Selects the frequency channel to be used by the network (usually the one with the least detected activity)
- Starts the network
- Allows other devices to connect to it (that is, to join the network)

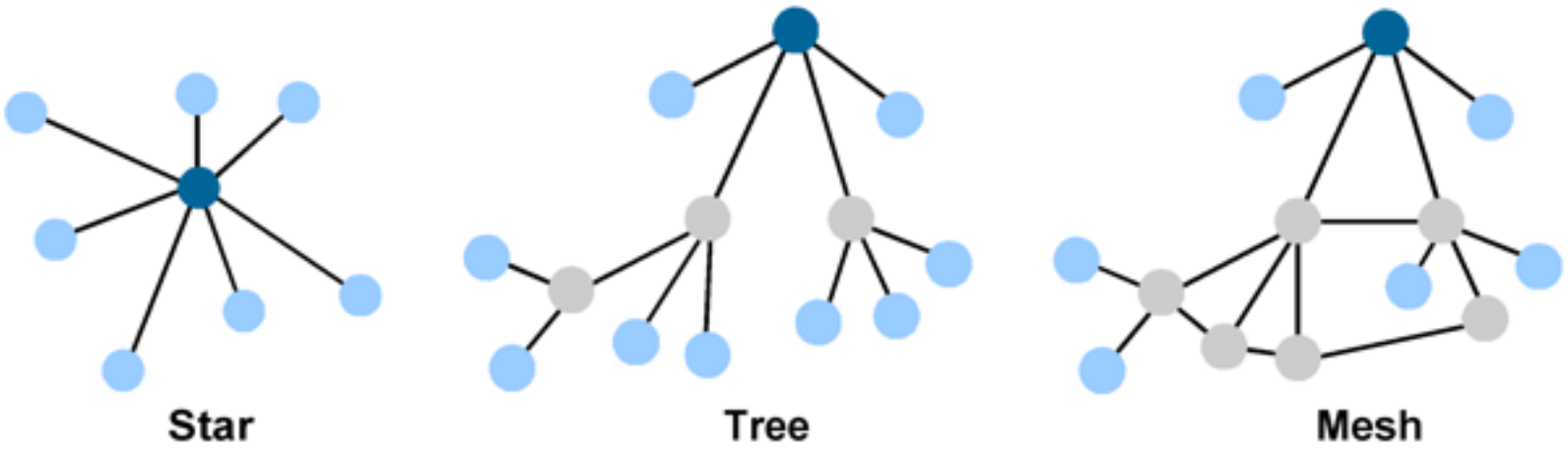
The Co-ordinator can also provide message routing (for example, in a Star network), security management and other services.

Zigbee - node types

End Devices are always located at the extremities of a network:

In the Star topology, they are perimeter nodes

In the Tree and Mesh topologies, they are leaf nodes



Zigbee - node types

The main tasks of an **End Device** at the network level are sending and receiving messages. Note that End Devices cannot relay messages and cannot allow other nodes to connect to the network through them.

An End Device can often be battery-powered and, when not transmitting or receiving, can sleep in order to conserve power.

Zigbee - node types

Networks with Tree or Mesh topologies need at least one **Router**. The main tasks of a Router are:

Relays messages from one node to another. Allows child nodes to connect to it.

In a Star topology, these functions are handled by the Co-ordinator and, therefore, a Star network does not need Routers.

Zigbee - node types

In Tree and Mesh topologies, Routers are located as follows:

- In a Tree topology, Routers are normally located in network positions that allow messages to be passed up and down the tree.
- In a Mesh topology, a Router can be located anywhere that a message passing node is required.

Note that a Router cannot sleep.

Zigbee - characteristics

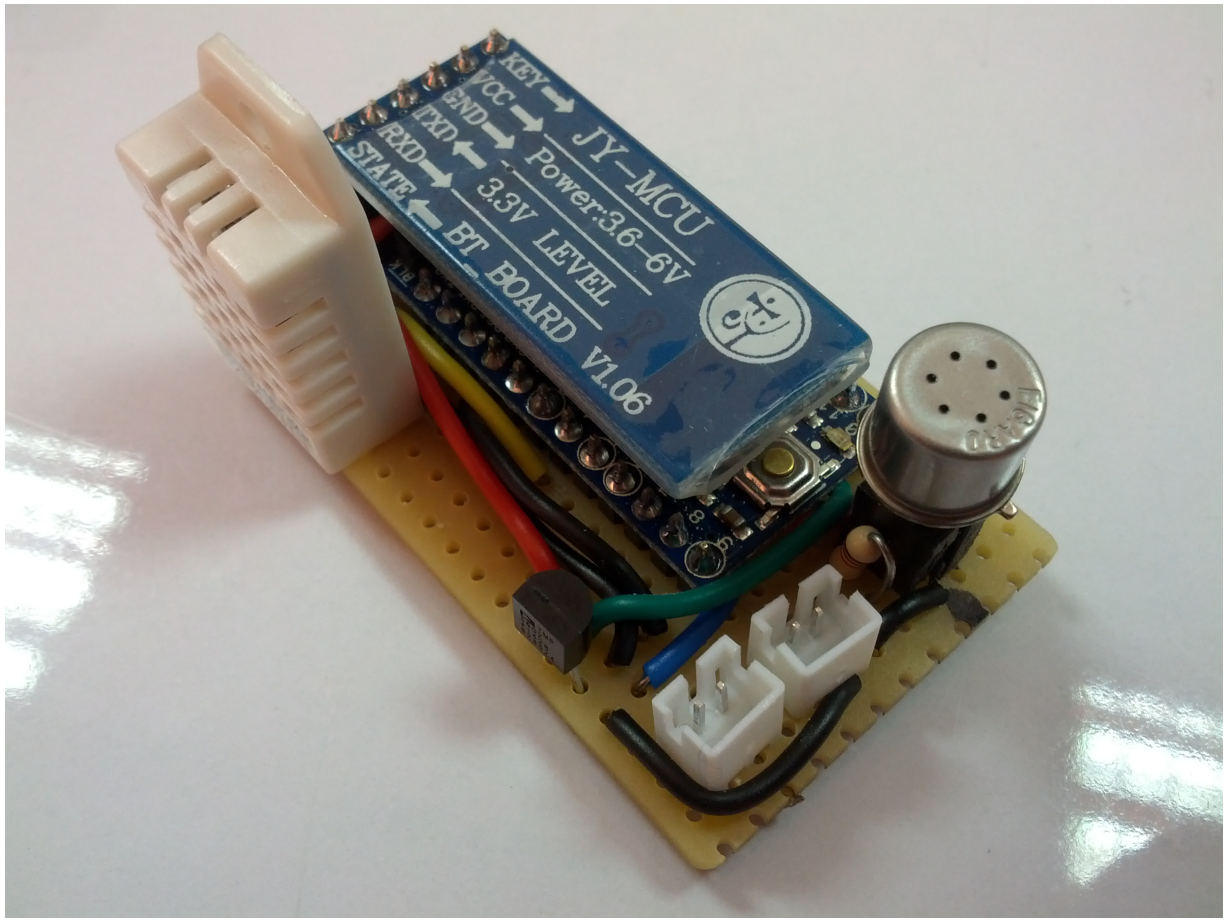
1.	Range	10m
2.	Multihop capabilities	yes
3.	Battery consumption	low
4.	Security	yes
5.	Cost (device)	low
	Cost (service)	free
	Availability	good
	Regulation	good

Bluetooth, especially Bluetooth LE (low energy)

Not typically considered a typical WSN option

However, a good option especially for integration with mobile phones / devices, human sensing, or for communication with gateways over a short range

Bluetooth



Air quality/temp/humidity sensor with serial-BT, http://bAIR.dk

Bluetooth - characteristics

1.	Range	30 m
2.	Multihop capabilities	no
3.	Battery consumption	mid
4.	Security	no
5.	Cost (device)	low
	Cost (service)	free
	Availability	good
	Regulation	good

WiFi based WSN

Advantage: use existing WiFi network infrastructure.

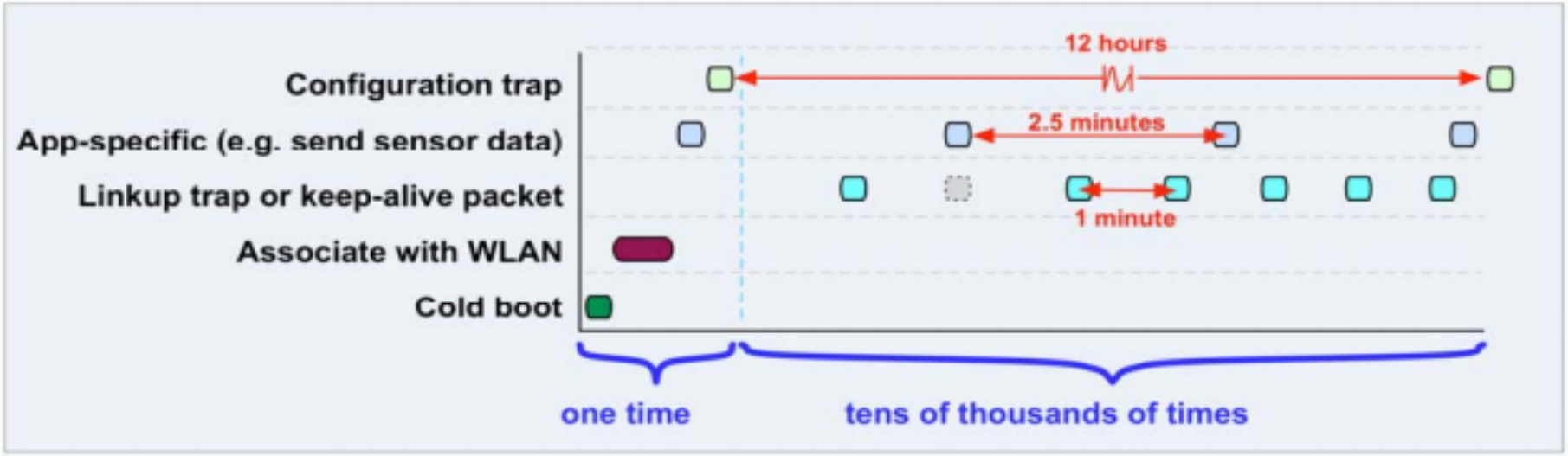
High power Wi-Fi chips are optimized for fast response, low latency, and high data rates.

Low power Wi-Fi chips are optimized for low power consumption, particularly when the device is in Standby mode.

WiFi based WSN

Parameter		Conventional Wi-Fi	Low-Power Wi-Fi	units
Power consumption	Standby / Idle	NA*	<4	µW
	Processor + clock sleep	13	0.2	mW
	Data processing	115	56	mW
Receive sensitivity, 1 Mbps		-91	-91	dBm
Time to wake from Standby		NA*	10	ms
Time to wake from processor+clock sleep		75	5	ms

WiFi based WSN

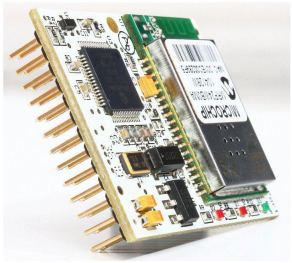


WiFi based WSN

Examples

The **XBee Wi-Fi** modules from Digi International come in 1mW and 2mW versions.

The **Flyport** provides the following services: Webserver (even Ajax apps can be run), TCP Socket, UDP Socket, SMTP Client.



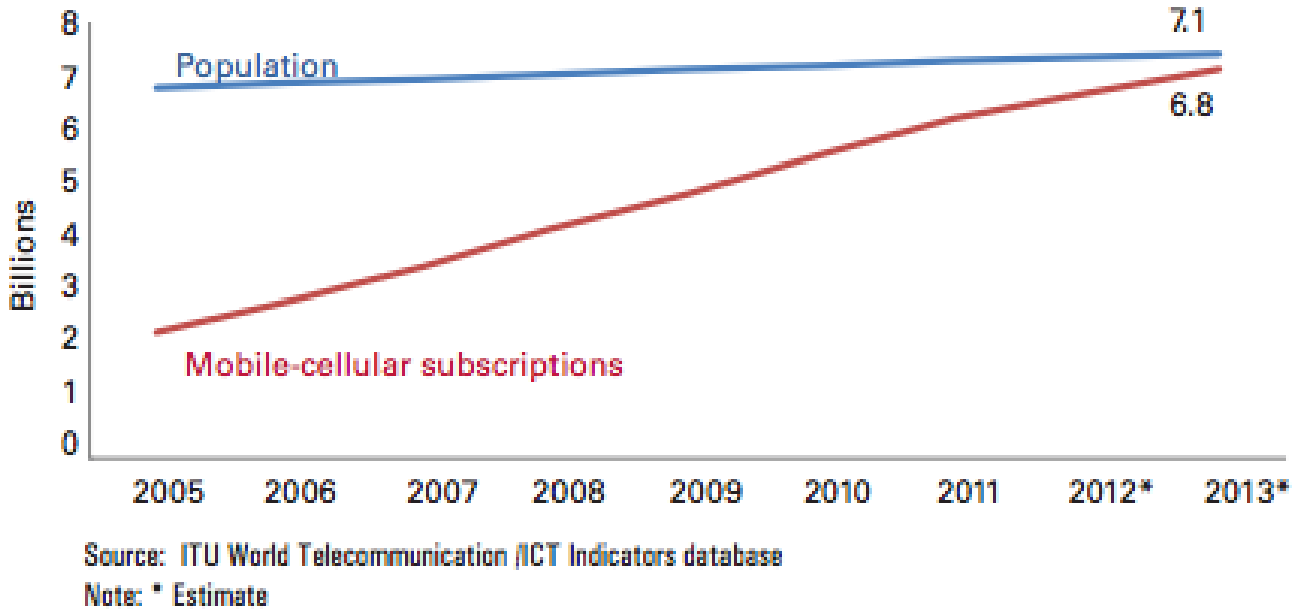
The **Gainspan** modules.

WiFi based WSN: Arduino WiFi Shield

Low Power WiFi - characteristics

1.	Range	100m
2.	Multihop capabilities	no
3.	Battery consumption	low
4.	Security	yes
5.	Cost (device)	medium
	Cost (service)	free
	Availability	good
	Regulation	good

GSM - widely available

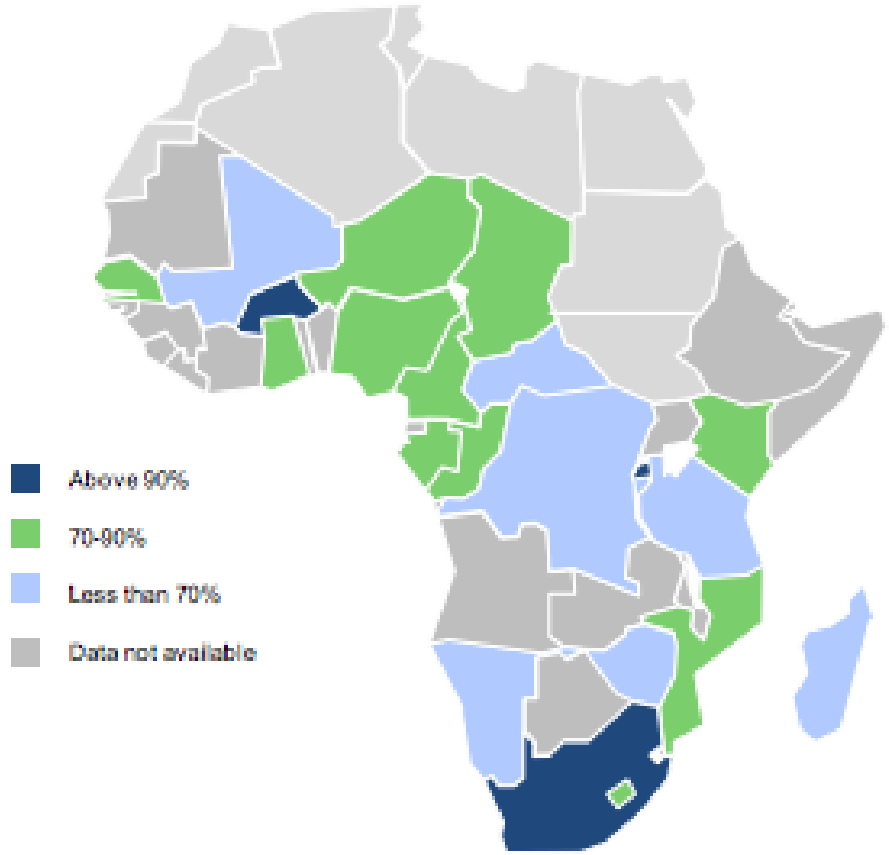


Source: ITU World Telecommunication /ICT Indicators database
Note: * Estimate

Africa is the region with the highest growth rates over the past three years and mobile-broadband penetration has increased from 2% in 2010 to 11% in 2013.

GSM - coverage

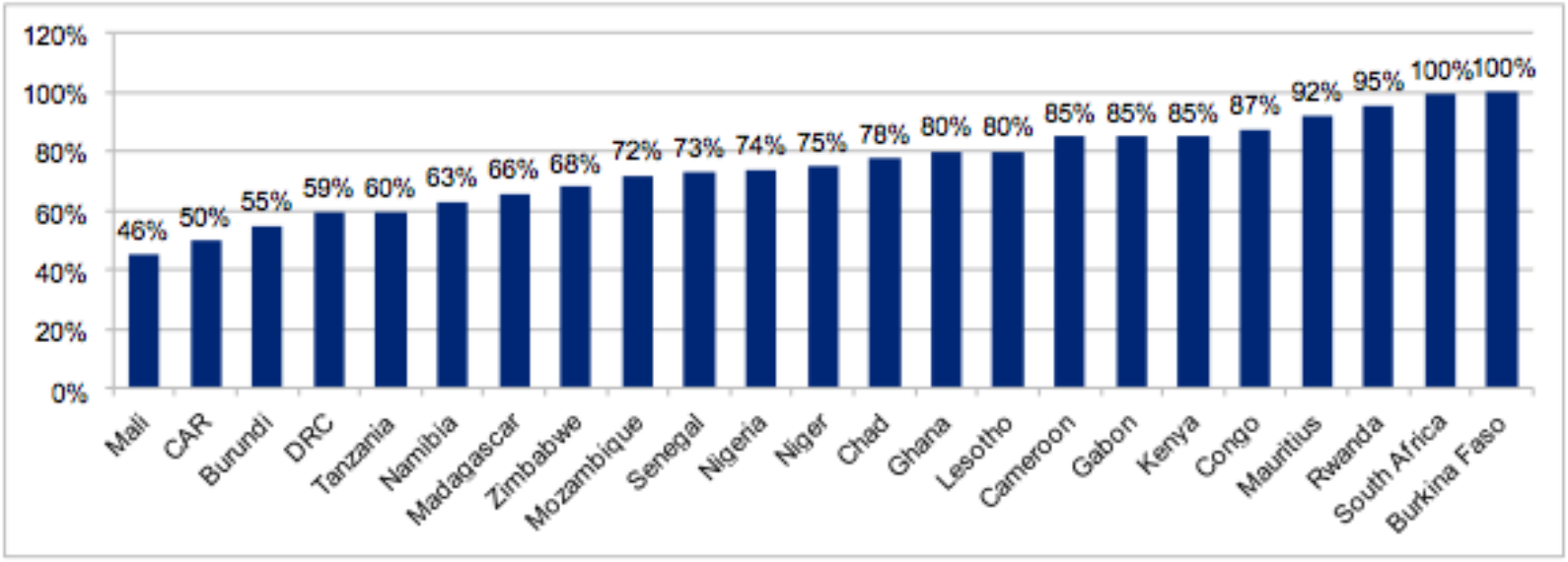
Figure 16: Coverage by country (2012)



Source: Wireless Intelligence

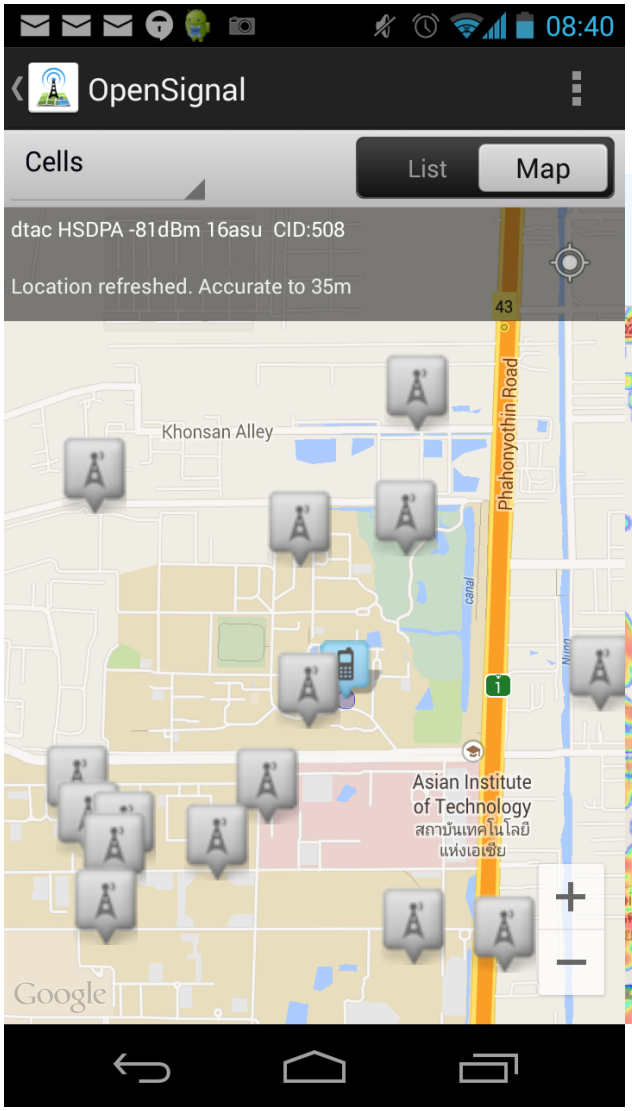
GSM - coverage

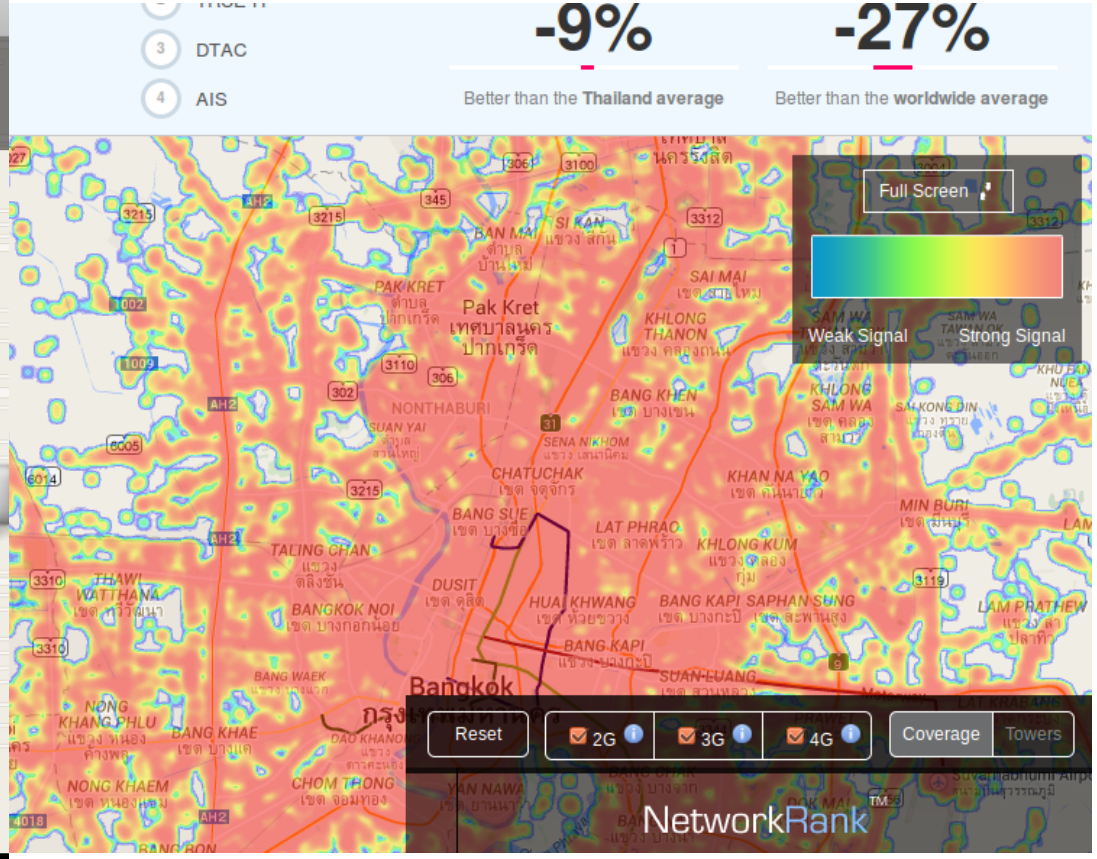
Figure 17: Coverage levels in selected SSA countries (2012)



Source: Wireless Intelligence. Data for available countries

GSM – verifying coverage





GSM - costs

By early 2013, the price of an entry-level mobile-broadband plan represents between 1.2-2.2% of monthly GNI p.c. in developed countries and between 11.3-24.7% in developing countries, depending on the type of service.

GSM: GPRSbee


SIM900
S2-10405-Z0955
GPRSbee Rev.4


SIM900
S2-10405-Z0955
GPRSbee Rev.4

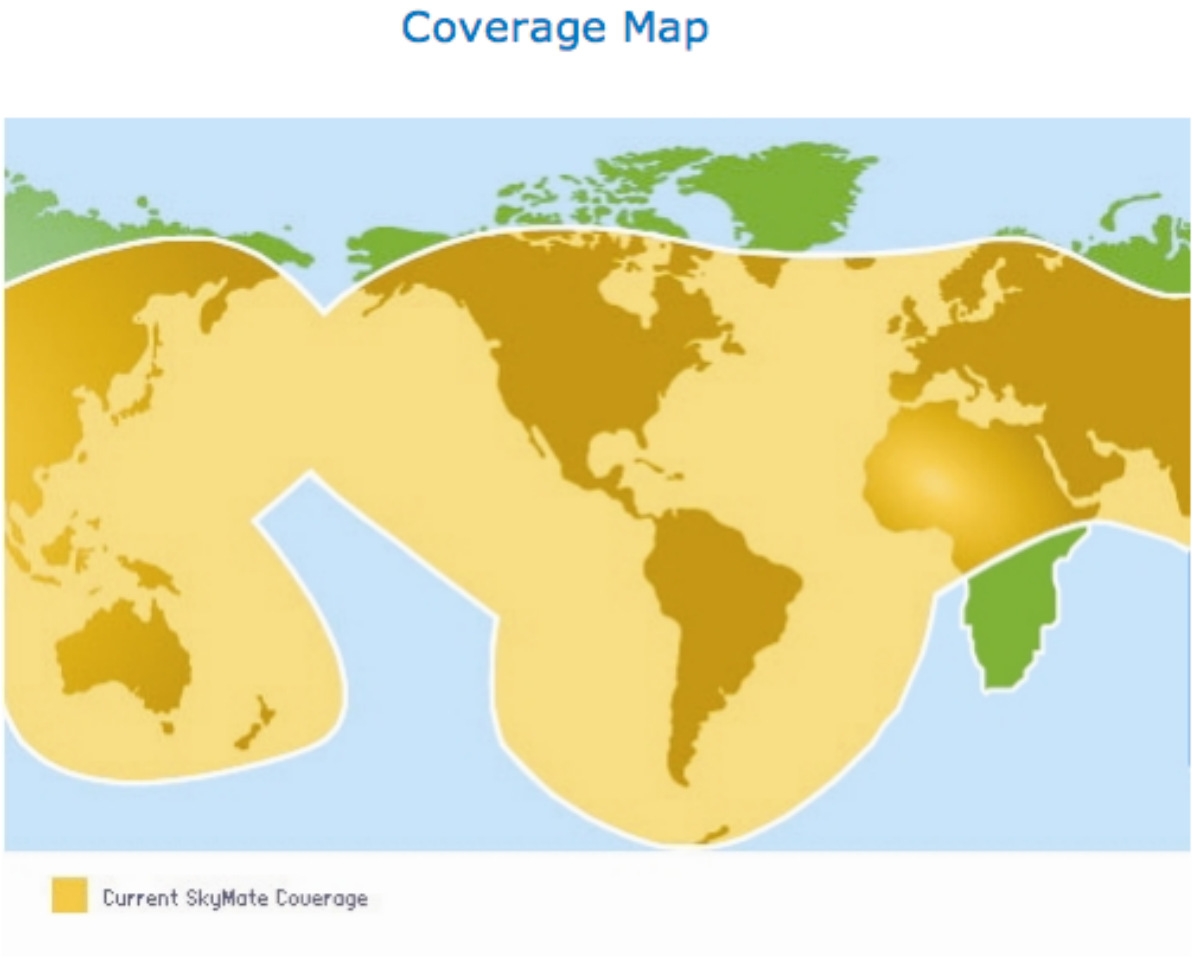
GSM - characteristics

1.	Range	infinite (…)
2.	Multihop capabilities	no
3.	Battery consumption	medium
4.	Security	no
5.	Cost (device)	medium
	Cost (service)	high
	Availability	medium
	Regulation	good

Satellite

1. Digi m10 satellite modem
2. $139.00

Satellite



Satellite

Platinum Plan

Send or receive 50,000 characters per month for just $69.99. Additional data costs only $1.40 per 1000 characters.

Gold Plan

Send or receive 20,000 characters per month for just $34.99. Additional data costs only $1.90 per 1000 characters.

Silver Plan

Send or receive 8,000 characters per month for just $17.99. Additional data costs only $2.25 per 1000 characters.

Satellite - characteristics

1.	Range	infinite
2.	Multihop capabilities	no
3.	Battery consumption	high
4.	Security	no
5.	Cost (device)	medium
	Cost (service)	medium
	Availability	low
	Regulation	poor

TV White Spaces

In telecommunications, **white spaces** refer to frequencies formerly used for broadcasting services but not used locally.
Exact frequencies and utilization depending on country,

e.g. 470 – 790 MHz available in many regions

Use of TVWS in WSN still unknown, depending on low cost chips

TVWS – future potential?

Aviacomm

Product Bulletin

ARF3010

Wideband RF Transceiver IC

Product Description

The ARF3010 is a wideband, low power, direct conversion RF transceiver designed for 3G/4G LTE cellular, TVWS, and other wireless protocols. The ARF3010 can be rapidly configured to operate on any frequency band between 50MHz and 2.8 GHz, and for different bandwidth signals, without restrictions of band-limited ports. This enables more efficient and scalable RF front-end designs.

Feature Summary

Broadband tunable RF transceiver

- Performance meets multiple standards
- 4G/LTE, WCDMA, TD-SCDMA, TVWS compatible

Direct Conversion, 2RX and 1TX

- MIMO/Diversity support

Specification Summary

Tuning Range	50 MHz - 2.8 GHz
Channel Bandwidths	0.5 - 40MHz programmable
RX noise figure	3.3dB
RX gain control	99 dB, 1 dB step
TX gain control	66 dB, 0.5 dB step

WSN communications options - Overview

	Range	Power	Data Rate	Mesh	Security	Cost (Device)	Cost (Service)	Availa-bility	Regu-lations
802.15.4	10 m	low	low	no	no	low	free	+	+
Zigbee	10 m	low	low	yes	yes	low	free	+	+
Bluetooth	30 m	low	high	no	no	low	free	+	+
WiFi	100 m	low-mid	high	(yes)	yes	mid	free	+	+
GSM	N/a	mid	high	no	no	mid	high	+-	+
Satellite	N/a	high	mid	no	no	mid	mid-high	+	+
TVWS	10 kms	?	high	(yes)	yes	?	free?	?	?

Thanks

Marco Zennaro

mzennaro@ictp.it

www.wsnblog.com