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Towards Ubiquitous Connected Objects that also Connect Outside the Home

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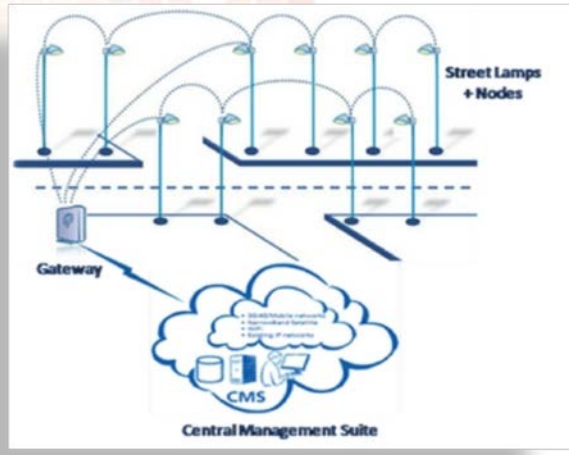
Plan..

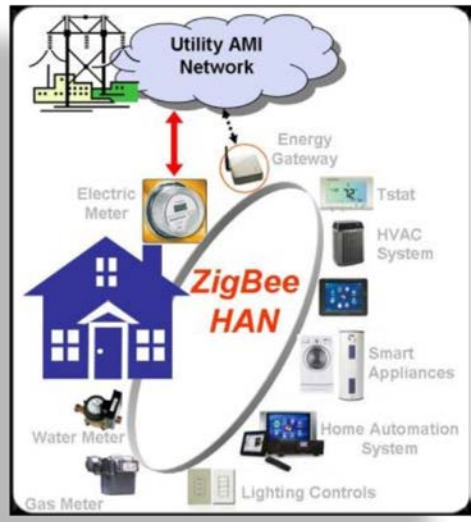
- What is radio range ?
- Link budget and data rate
- Network topology
- Protocol & Device battery life
- A quick look at the future.

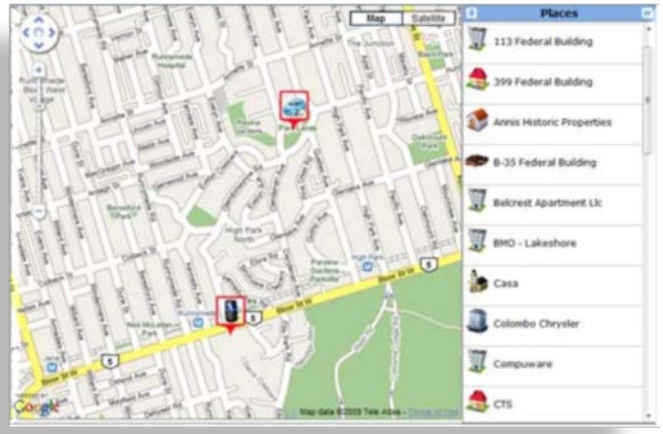
Bringing connectivity to any object

IoT covers hundreds of applications with a corresponding number of custom wireless or wired technologies



- *WMBus*
- *Wireless HART*
- *Zigbee*
- *Wifi*
- *BT Low Energy*
- *GPRS/3G/4G*





Inside and Outside the Smart Home

Typical “Smart Home” applications we are interested in:

- **HVAC control , connected thermostats**
- **Security**
- **Leak detection , water/gaz valve remote control**
- **Pet tracking**
- **Asset tracking (car, bikes, parcels, …)**
- **Garden irrigation**
- **Energy management (fridge , oven, water heater)**
- **Water, Gaz, Electricity metering**

IoT network technical requirements

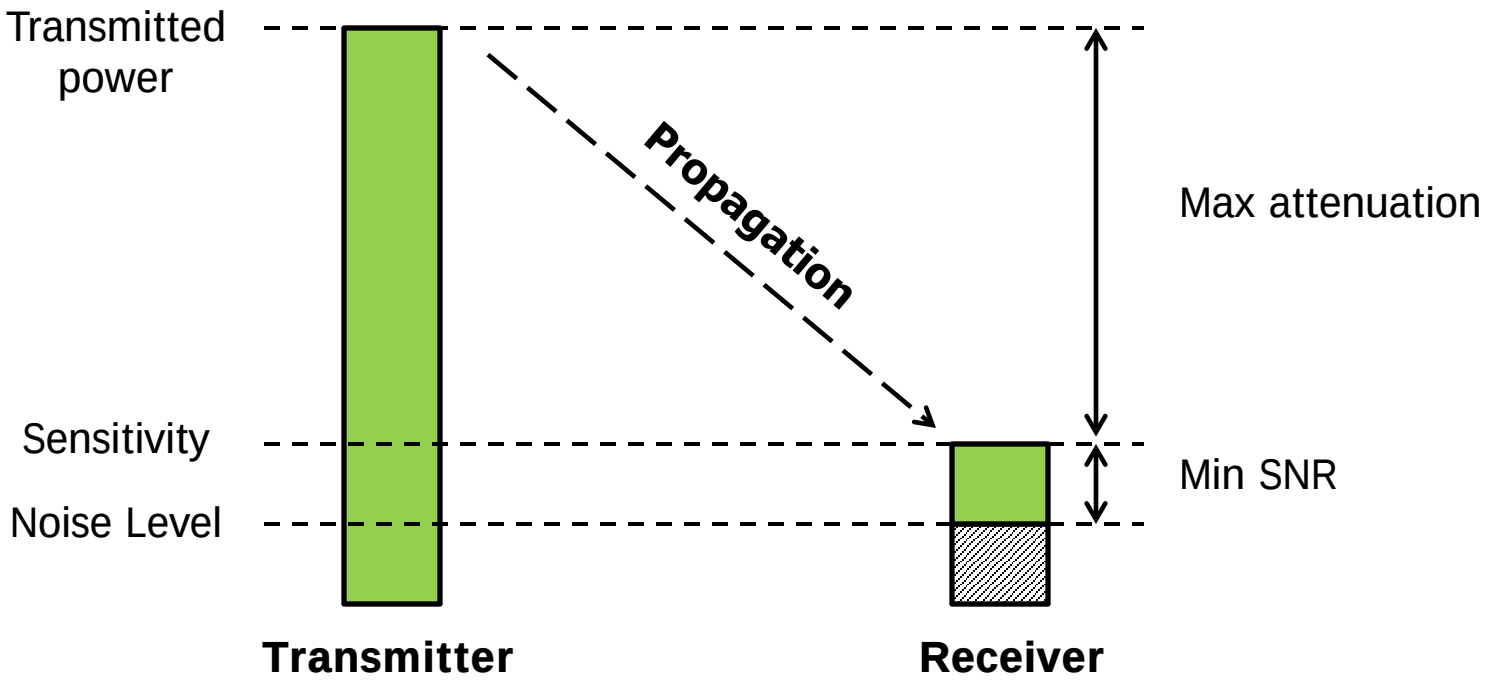
Cellular like

- Long range communication for indoor/outdoor coverage
- Mobile devices
- Permanent service
- Simple pairing, should work out of the box

Specific to IoT

- Ultra Low power device implementation for long battery life
- Low cost device radio chipset and operation

Long range radio communications …



Radio range is a (vague) function of the maximum signal attenuation (or Path Loss) tolerated by the communication system.

Path Loss…

- **Free Space Path Loss**

$$FSPL(dB) = 10\log_{10}\left(\frac{4\pi df}{c}\right)^2$$

- **Real Life Path Loss**
  - Buildings
  - Fresnel
  - Fading

900MHz	L.O.S	Indoor	Underground
1km	92dB	115dB	140dB
2km	98dB	125dB	150dB
10km	112dB	140dB	?
800km	150dB		

Path Loss…

Path Loss varies widely with pretty much everything:

- **Environment**
- **Antennas exact location**
- **Channel frequency (fading)**
- **Time**
- **Weather**

900MHz	L.O.S	Indoor	Underground
1km	92dB	115dB	140dB
2km	98dB	125dB	155dB
10km	112dB	140dB	?
1600km	155dB		

The “pesky” laws of physics …

Longer range ⇨

- ❑ **Higher transmit power**
- ❑ **Better receiver sensitivity**
- ❑ **Higher antenna gain**

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Thermal Noise :

$$P_{\mathrm{dBm}} = -174 + 10\ \log_{10}(\Delta f)$$

Shannon capacity limit: Upper bound on the bit rate for a given channel bandwidth and Signal to Noise Ratio (SNR)

The “pesky” laws of physics …

The ultimate sensitivity limit:

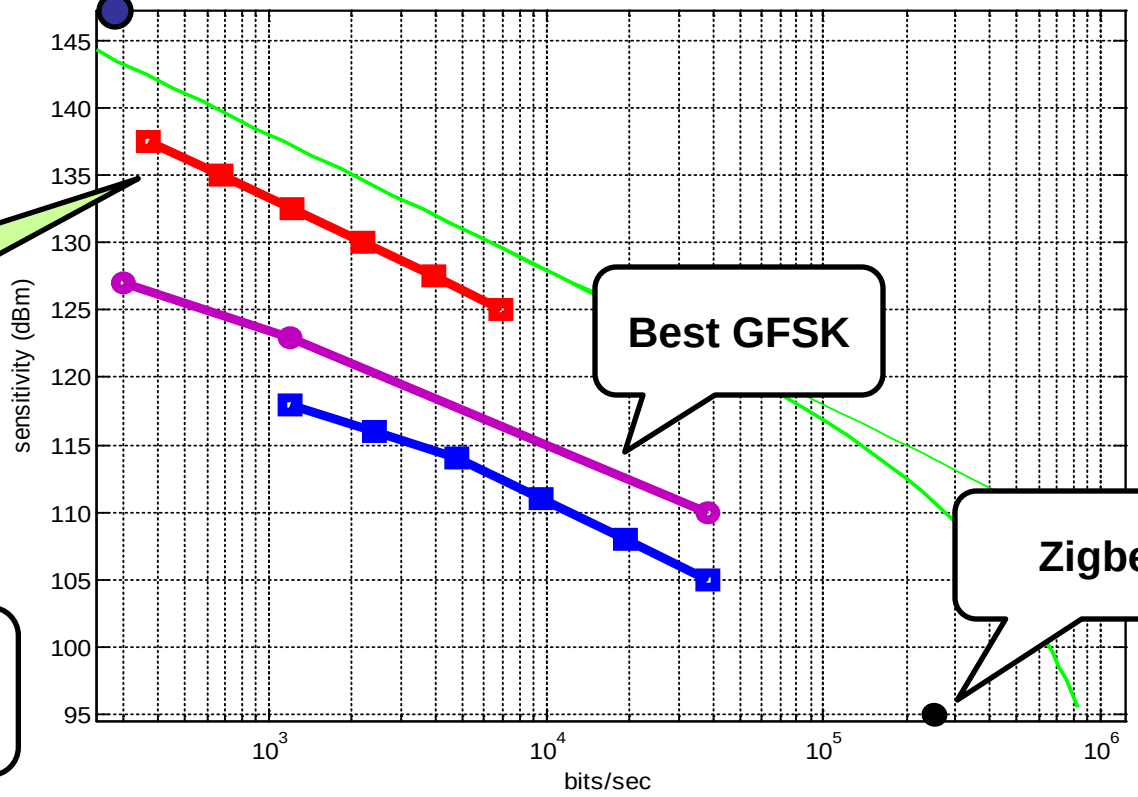
Deep Space network “voyager” downlink

LORA device

Best GFSK

Zigbee

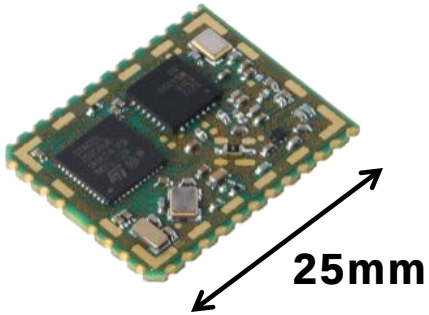
Marconi 1901 cross-channel



A quick comparison .. ☺

One of the most sensitive (nitrogen cooled) receiver currently used mounted on a 70m dish antenna
-150dBm @ 160bit/sec

LORA dual band (433/900MHz) module
-141dBm @ 150bit/sec



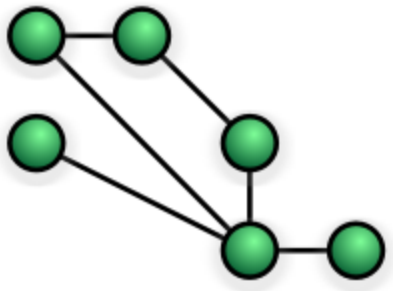
Typical system Link Budget

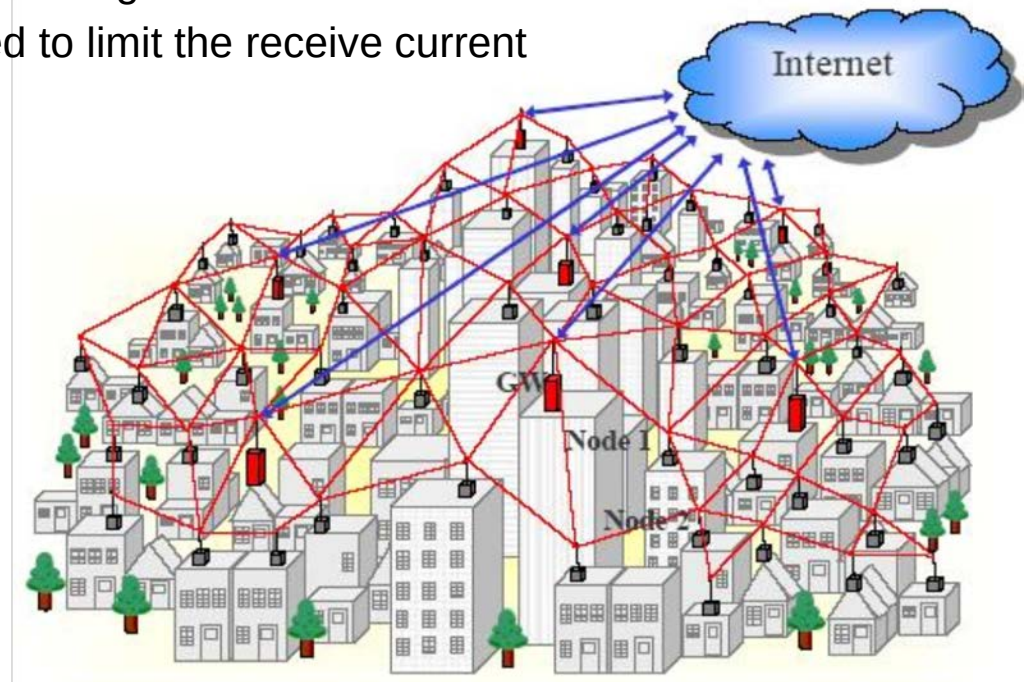
System	Data rate	TX power (dBm)	Receiver Sensitivity (dBm)	Receiver ANT gain	Max Path Loss
Wifi @ 2.4Ghz	1Mbit/s	+17	-95	3dBi	112dB
ZigBee @ 2.4Ghz	250kbit/sec	+1	-97	-3dBi	98dB
BT LE @ 2.4Ghz	1Mbit/s	+4	-93	-3dBi	97dB
2GSM	144kbit/s	+30	-110	+18dBi	158dB
868Mhz LORA	300b/sec	+14	-142	+6dBi	162dB
	6.6kbit/sec		-128		148dB

A 20mW LORA device talking to an omnidirectional gateway antenna achieves the same range than a 1W GSM talking to a sectored base-station

The wireless Mesh network solution ….

- **Theoretically : lowest possible power and robust**
- **A node only need to reach his neighbors**
- **But major show stopper: route discovery and synchronization**
  - As soon as nodes start to move , routing tables transfer stalls the network
  - All nodes need to be synchronized to limit the receive current

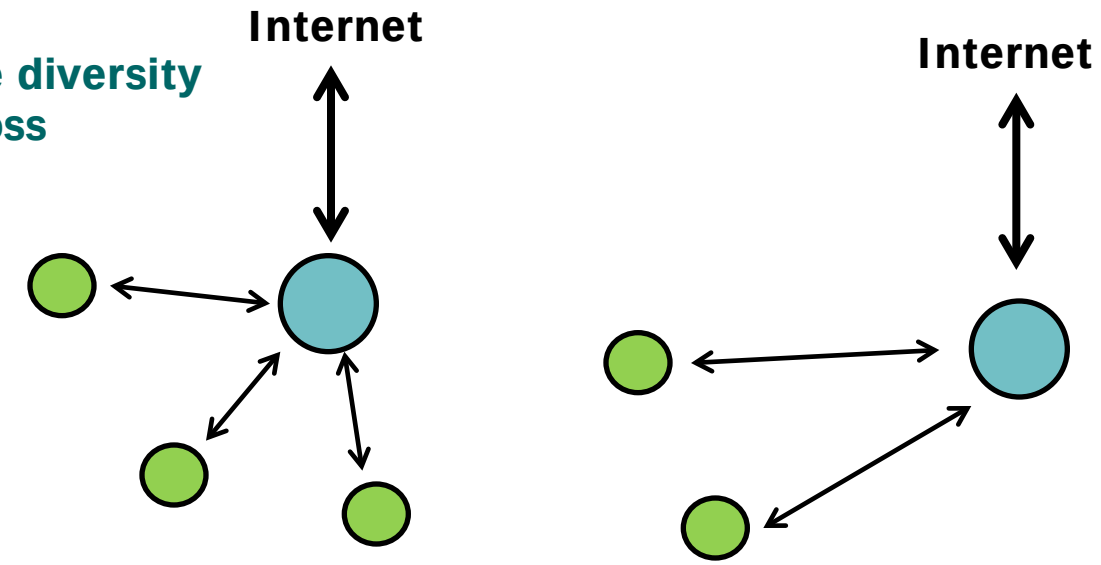




The “star” topology

- Nodes are paired to a gateway
- Each gateway only listens to its own sub-net channel

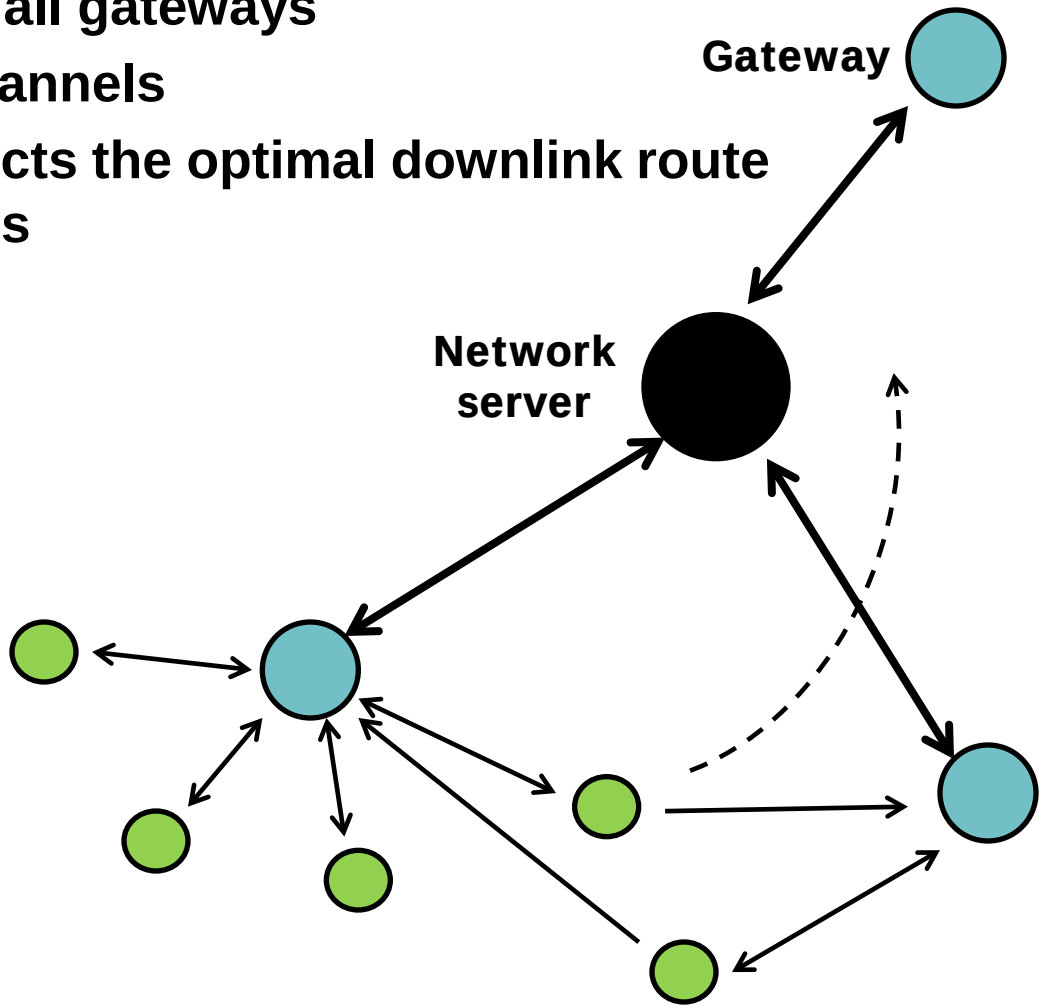
- No mobility
- No Spatial uplink receive diversity
- Not robust to gateway loss



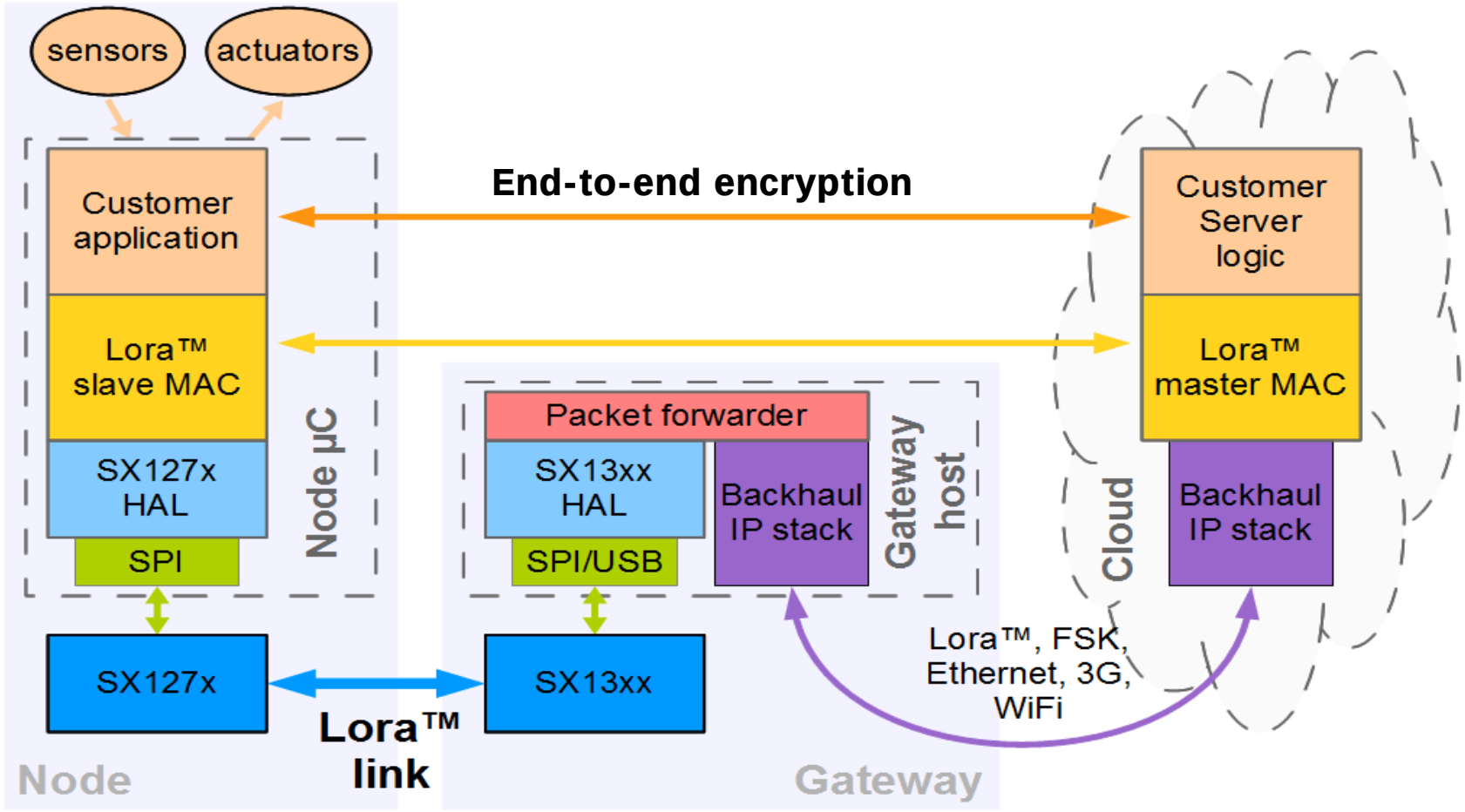
“Multi-star” topology , bringing in mobility.

- ❑ Nodes are not paired to a gateway
- ❑ Uplinks can be received by all gateways
- ❑ All gateways listen to all channels
- ❑ Central network server selects the optimal downlink route on a packet per packet basis

- Supports mobility
- Spatial uplink receive diversity
- Robust to gateway loss



The “dumb” gateway



Ultra-low power operation …

Sending 30bytes applicative payload 10x a day

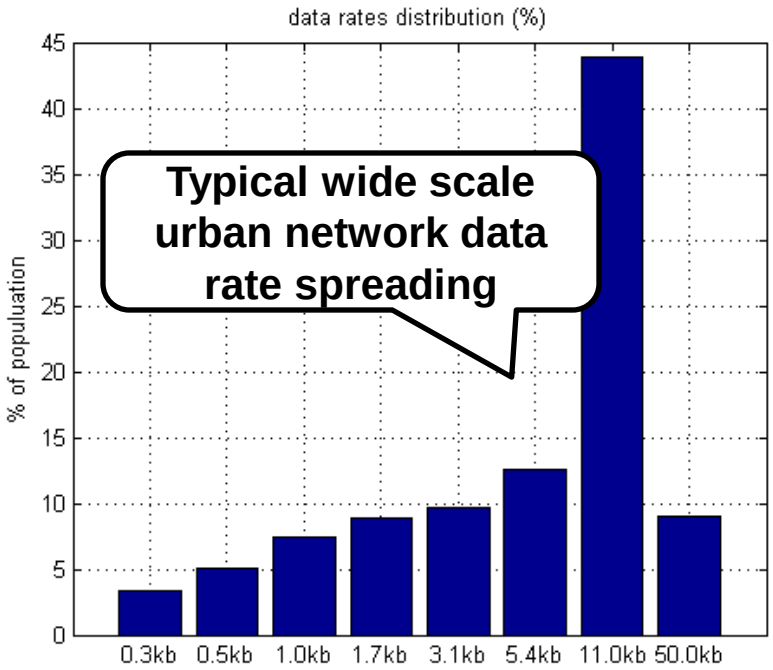
Technology	Energy (J) per message	1000mA/h battery life	Peak current
Cellular SMS (**)	120 + 1.72	10 days	480mA
Wifi (*)	5	230 days	100mA
Lora 300b/s	0.2	16 years	30mA
Lora 6kbit/s	0.0095	~340 years ☺	30mA

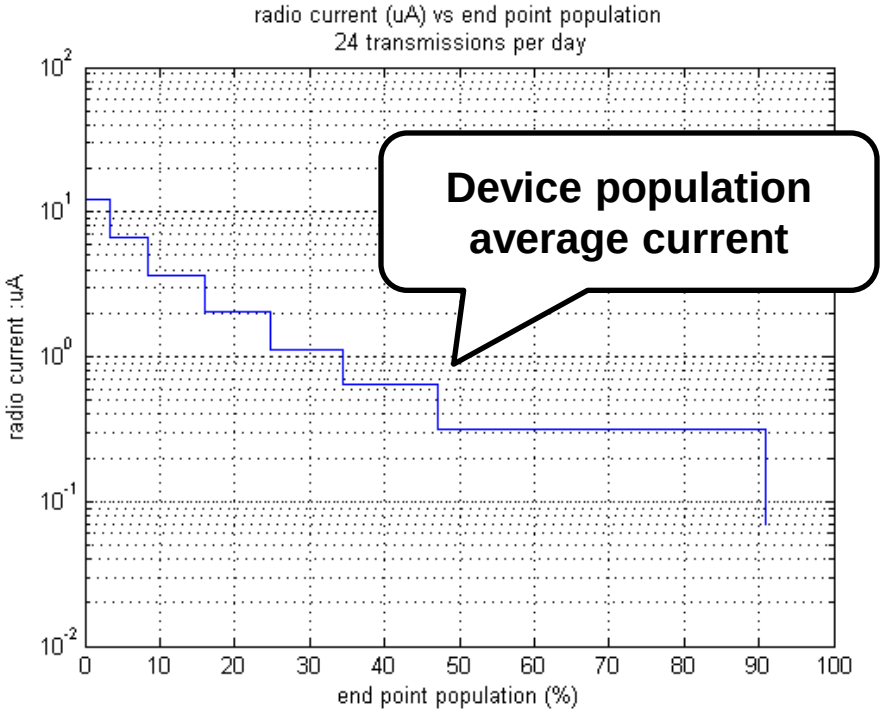
- **Low power is essentially a protocol issue**
- **Lora uses an asynchronous access method : no network access fixed cost**

(*) “Energy consumption analysis for Bluetooth Wifi and Cellular Networks”, Rahul Balani, UCLA
(**) “Survey on Energy Consumption Entities on the smartphone Platform”,G.P Perrucci, Nokia
(**) www.iskraemeco.si/emecoweb/eng/products/bdf/P2W_ang.pdf

Adaptive Data Rate

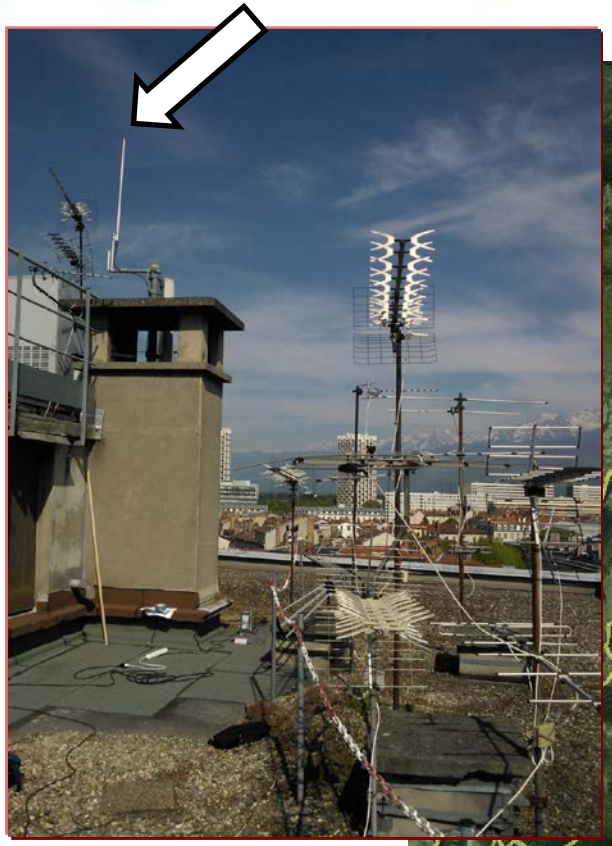
- **Trading efficiently "data rate" for "sensitivity" is key**
  - Vastly increases the average device battery life
  - Multiply the total network capacity by > x10

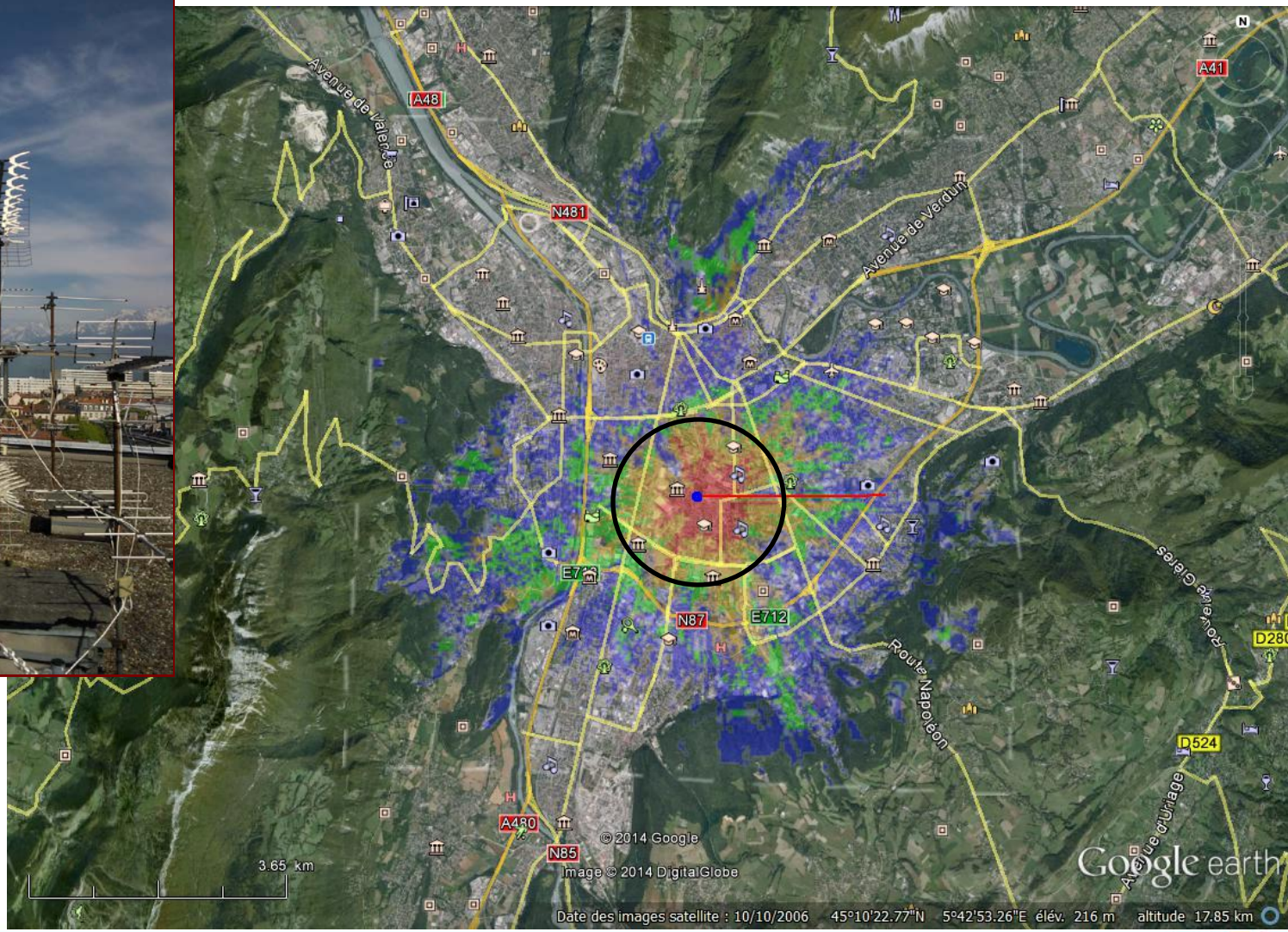




Single gateway urban coverage ..

Deep indoor : 1km
Outdoor : 3 to 5km





Conclusion

Cellular like

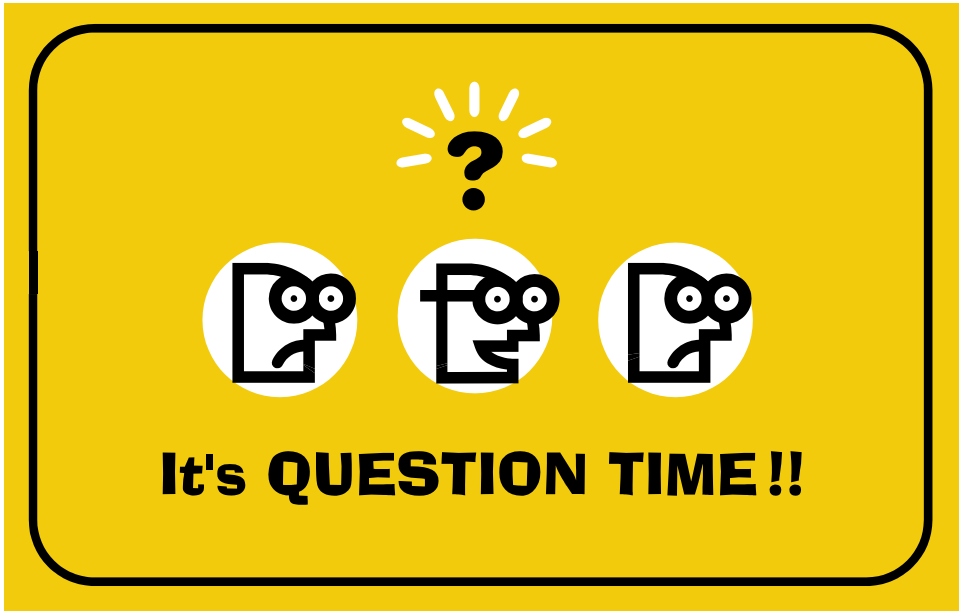
- Long range communication for indoor/outdoor coverage
- Supports mobile devices
- Permanent service : operated infrastructure
- No pairing, connects out of the box

Specific to IoT

- Long device battery life
- Low cost device radio chipset and operation

A quick look into the future.

- **3dB left to be gained in modulation efficiency**
  - Lora is 4-5dB from the Shannon capacity limit
- **Antenna array beam steering is the way to go**
  - Potentially huge coverage improvement
  - How can we integrate it on a small device ?
  - How to make it cheap enough ?
- **Localization of every radio end-device with every packet**
  - Using Differential Time of Arrival method
  - Requires order of magnitude more processing on the gateway side
  - Creates entirely new use cases for the technology


It's QUESTION TIME!!