Connectivity for IoT

Enabling Communication Technologies for IoT

Learning Objectives

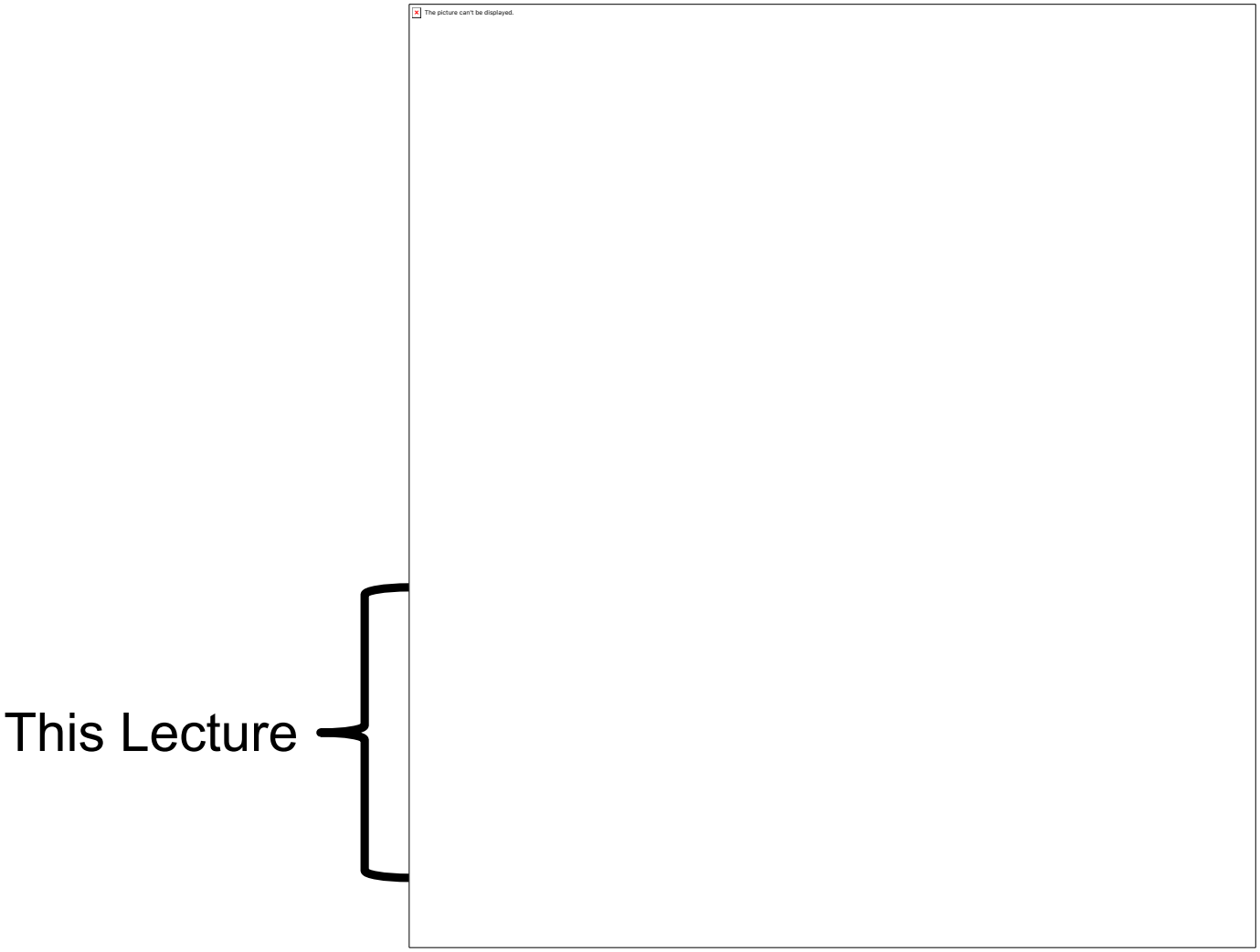
Upon completion of this chapter, the student should understand:

- The main attributes of the major competing wireless technologies
- How to interpret Physical/link layer specifications
- How to compare two radio modules
- The common impairments affecting radio performance
- How to select a suitable radio technology

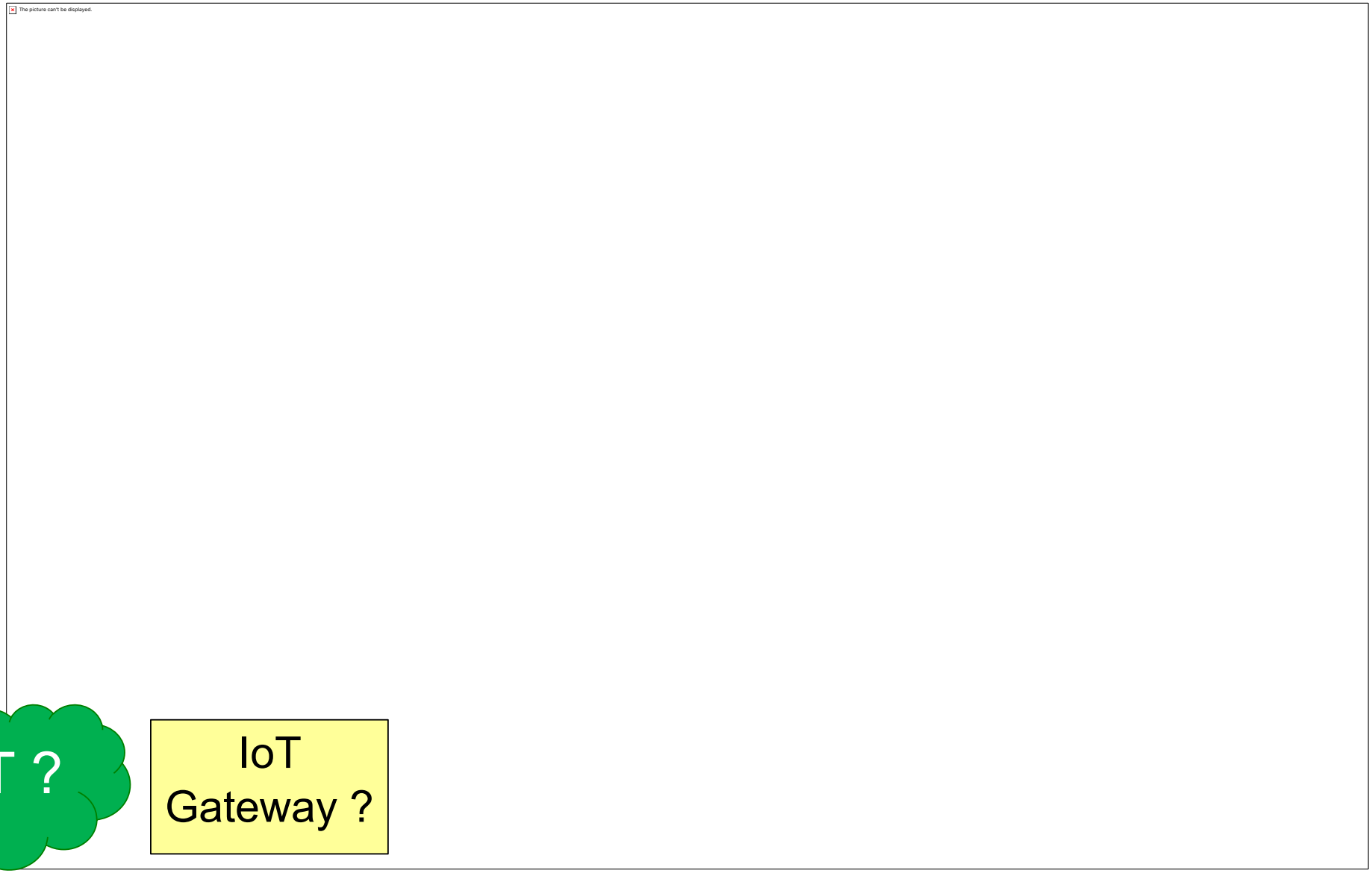
Outline

- Motivation
- Wireless Behaviour
- The Main Wireless Standards
  - Cellular, WiFi, ZigBee, Bluetooth, many others
- Selection of Suitable Technology for a given Application

The Protocol Stack



The Internet ..



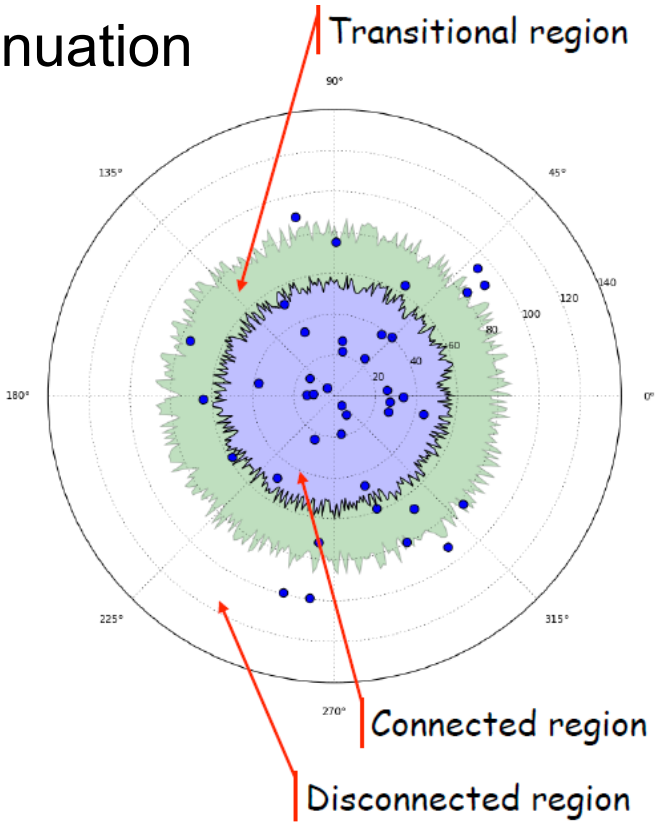
Frequency Allocation (Spectrum)

- Some frequencies are allocated to specific uses
  - Cellular phones, analog television/radio broadcasting, DVB-T, radar, emergency services, radio astronomy, ..
- Particularly interesting: ISM bands ("Industrial, scientific, medicine") – license-free operation

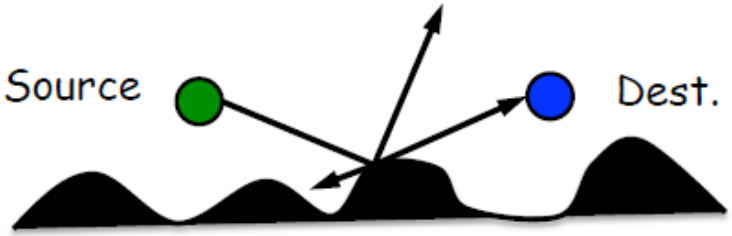
Some typical ISM bands	
Frequency	Comment
13,553-13,567 MHz	
26,957 - 27,283 MHz	
40,66 - 40,70 MHz	
433 - 464 MHz	Europe
900 - 928 MHz	Americas
2,4 - 2,5 GHz	WLAN/WPAN
5,725 - 5,875 GHz	WLAN
24 - 24,25 GHz	

Challenges on Physical Layer

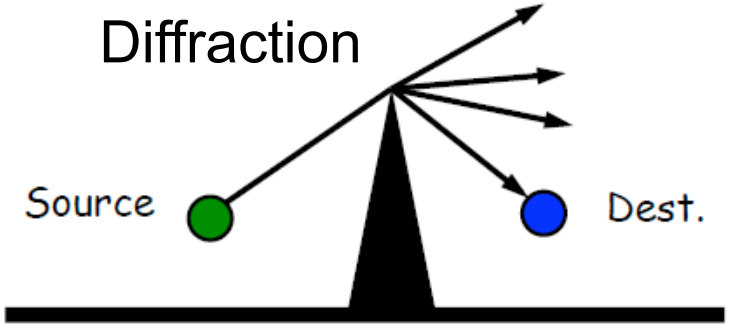
Attenuation



Scattering

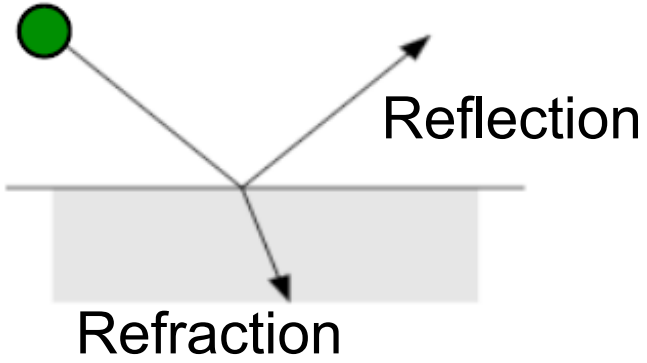


Diffraction

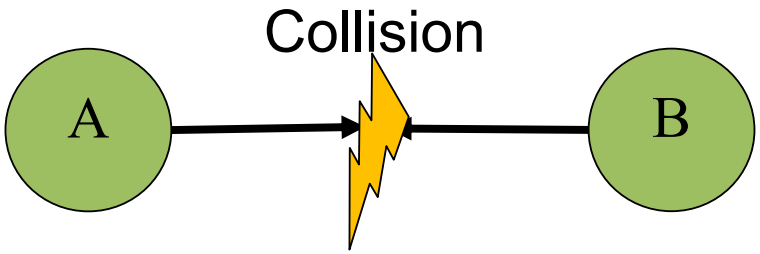


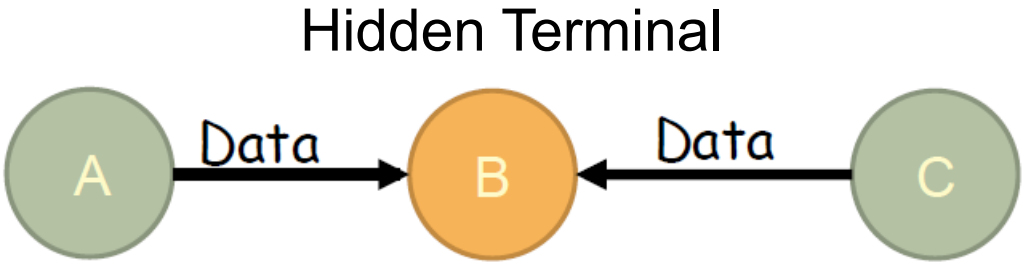
Line of Sight

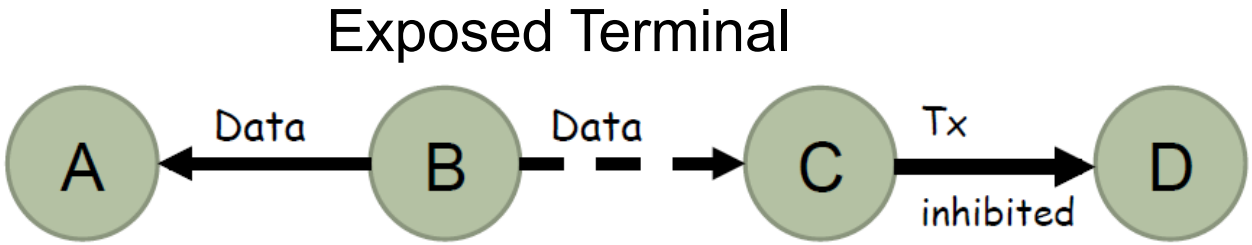
- Line of Sight
- Near Line of Sight
- No Line of Sight



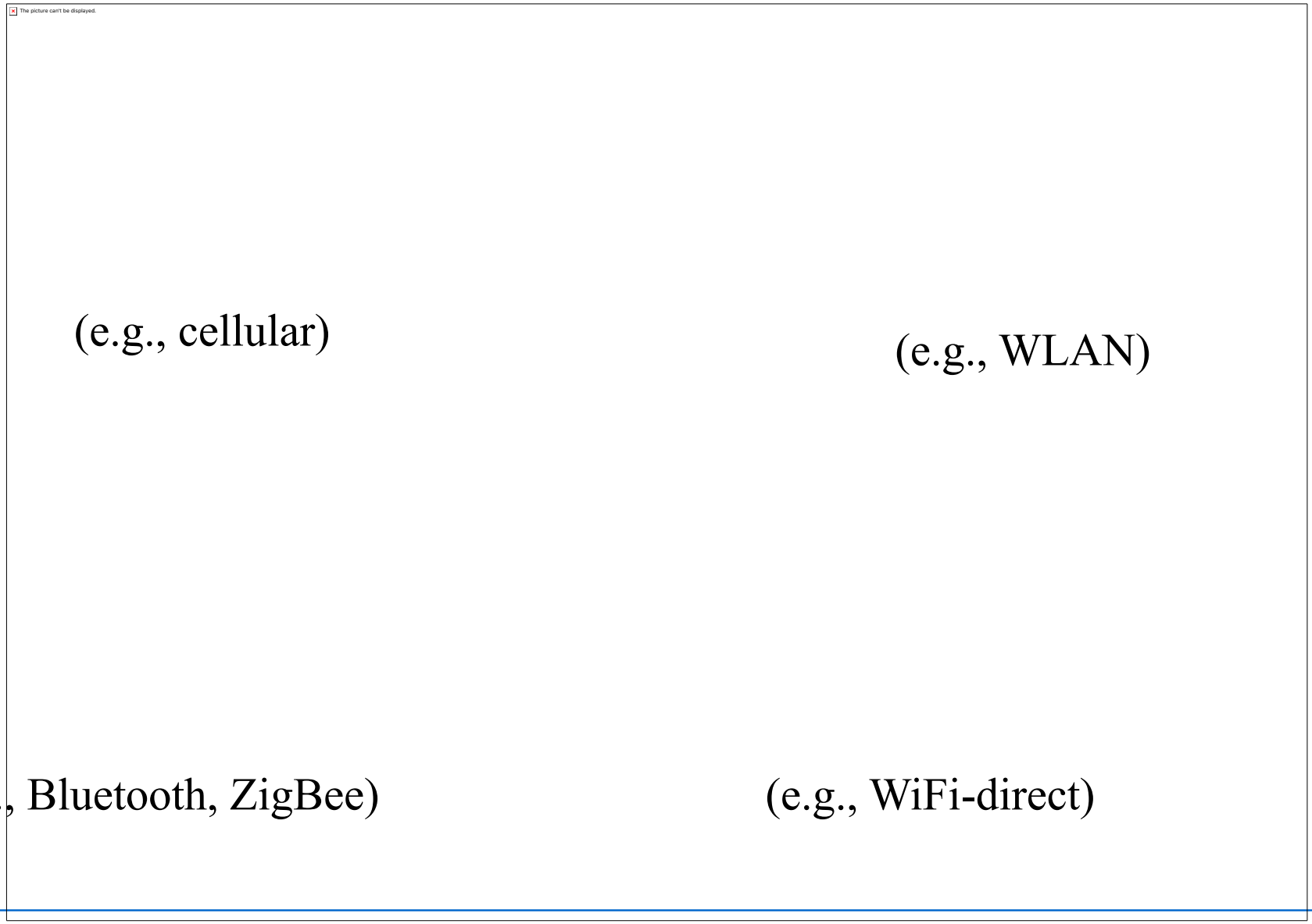
Challenges on Link Layer







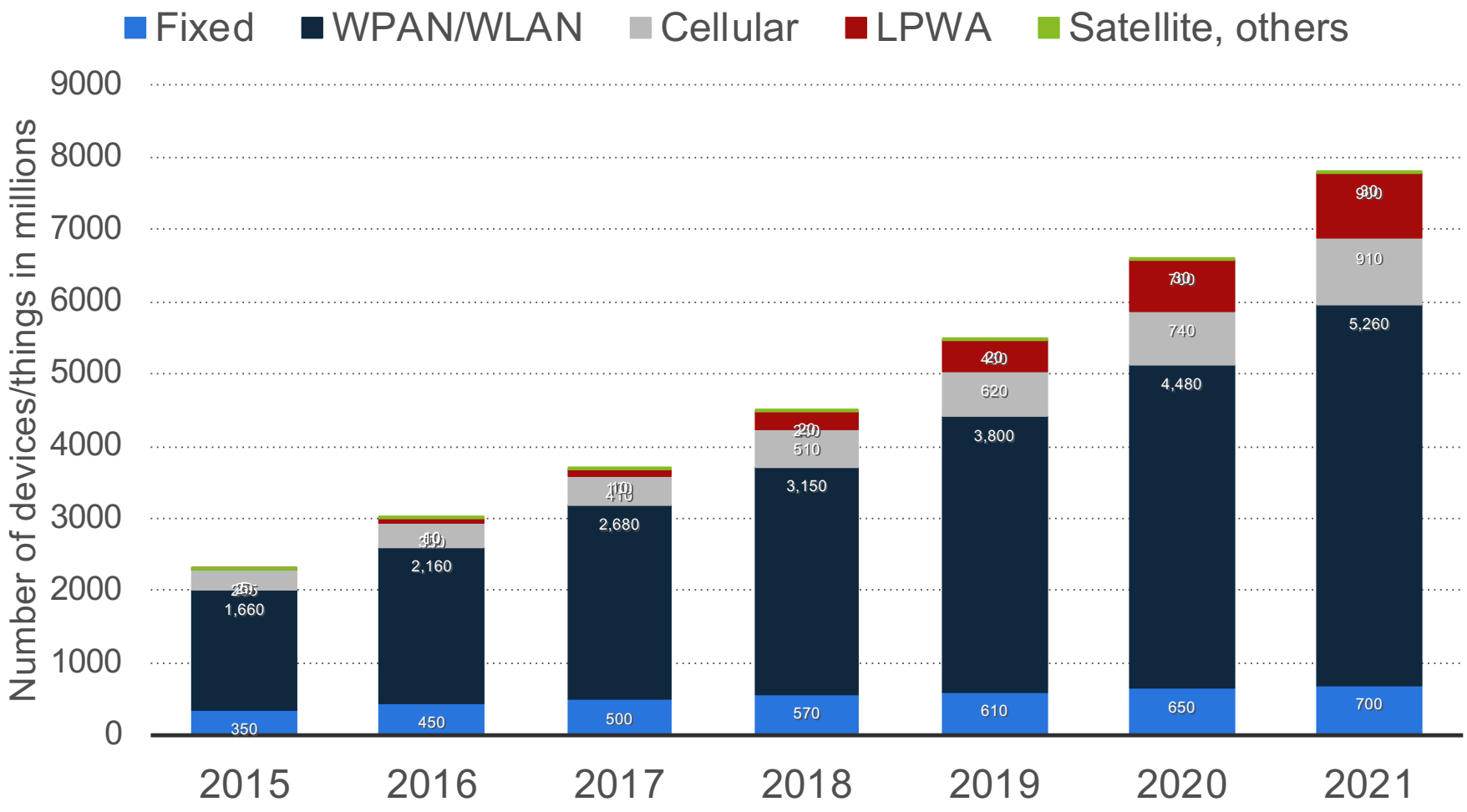
Topologies for Wireless Networks



Characteristics of wireless networks

- **Number of nodes:** number of all devices in the network, like routers, gateways, or hosts. The larger the number of nodes in a network, the more difficult it is to manage the network.
- **Mobility:** This key refers to mobile nodes in the network, for example mobile routers and mobile clients. A network with a higher degree of mobility usually exposes a higher dynamic topology.
- **Hop-Count:** number of hops between a source and destination. A high hop count is likely to increase the latency of transmissions and decrease the throughput of a network.
- **Self-Organization:** degree of human interaction required by a network, e.g., for configuration and management. Thus a network with a higher degree of self-organization is a network which demands less human interaction.
- **Energy-Awareness:** energy sensitivity of a network. A network has to be more energy-aware if the energy resource is finite.
- **Universality:** Characterizes whether the network is tailored to a specific application. A network is more universal if it can be used for more applications.
- **Data rate:** user-perceived throughput, for example the quality of a connection from a source to a destination. Usually, the higher the data rate, the better the connection throughput. However, this key has to be used carefully, since a wireless link may show low quality due to interference even with high data rates.

Enabling Technologies: Number of connected devices/things by technology worldwide



WPAN: Wireless Personal Area Network
WLAN: Wireless Local Area Network
LPWA(N): Low Power Wide Area (Network)

Source: Berg Insight; ID 626323

Connectivity Technology Considerations

Technical

Coverage determines where the devices can be deployed and connected

Energy efficiency affects battery life and maintenance cycle

Data rate limits the types of services that can be provided

Other technical features may be relevant for specific applications

Commercial

QoS ensures the value the IoT service can deliver

Security protects privacy and integrity of IoT users

Cost decides the business viability of implementing and operating the IoT service

Scalability determines the flexibility for managing growth

Ecosystem

Future proofness ensures the strategic investment in IoT is economically and technologically sustainable in the long run

Global reach and interoperability brings simplicity and efficiency to international IoT deployments

Src Telenor Connexion, 2016

Main Technologies for IoT

Considerations	Traditional Cellular			Cellular LPWA			Proprietary LPWA			Short Range		
	2G	3G	4G	LTE-CatM1	EC-GSM	NB-IoT	SigFox	LoRa	Ingenu	Wi-Fi low power	ZigBee 3.0	Bluetooth LE
Outdoor coverage	>10km	>10km	>10km	>10km	>15km	>15km	>15km	>10km	>15km	<1km	<300m	<100m
Indoor coverage	High	Medium	Medium	Medium	High	High	High	High	Very low	Very high	Medium	Low
Energy efficiency	2-5 years	<10 days	<10 days	>10 years	>10 years	>10 years	10-20 years	10-20 years	10-20 years	6-12 months	6-12 months	6-12 months
Typical uplink data rate	50 kbps	1 Mbps	10 Mbps	1 Mbps	200 kbps	20 kbps	100 bps	25 kbps	50 kbps	1 Mbps	250 kbps	1 Mbps
Bidirectional communication	Yes	Yes	Yes	Yes	Yes	Yes	Limited downlink	Yes in Class A	Yes	Yes	Yes	Yes
Mobility	Very high	Very high	Very high	Very high	High	High	Very low	Low	Medium	Medium	Low	Very low
Localization	Yes	Yes	Yes	Yes	Yes	n/a	No	Limited accuracy	n/a	Yes	Yes	yes
QoS & security	Very high	Very high	Very high	Very high	High	High	Very low	Low	Low	Medium	Medium	Medium
Device cost	$5-10	$15-30	$30-50	$20-40	$5-10	$5	$1-5	$1-5	$5-10	$5-10	$5	$5
Connectivity cost	Medium	High	Very high	High	Medium	Medium	Very Low	Low	Low	Medium	Medium	Medium
Scalability	High	High	High	High	Very high	Very high	High	High	High	Low	Low	Very low
Future proofness	Medium	Medium	Very high	High	Medium	Very high	Low	High	Low	Medium	High	High
Global reach & interoperability	Very high	Very high	Very high	High	High	High	Medium	Low	Very low	Low	Medium	High

Src Telenor Connexion, 2016

Main Characteristics of Short Range Communication (ZigBee, 6LowPAN, Z-Wave, BLE, Bluetooth)

		ZigBee	6LoWPAN (Over 802.15.4)	Z-Wave	Bluetooth Low Energy	Classic Bluetooth
Physical layer	RF band (MHz)	868/915/2400		868/908 (all chips) 2400 (400 serie chip)	2400	2400
	Bit rate (kbps)	20/40/250		9.6/40 (from 200 series chip) 200 (only 400 series chip)	1000	≤721(v1.2), 3000 (v2+EDR), ≤24,000 (v3+HS)
	Modulation	BPSK/BPSK/O-QPSK		BFSK	GFSK	GFSK (v1.2), GFSK/π/4-DQPSK/8DPSK (v2+EDR), 802.11 (v3+HS)
	Spreading technique	DSSS		No	FHSS (2 MHz channel width)	FHSS(1 MHz channel width)
	Receiver sensitivity (dBm)	−85 or better(2.4 GHz band)−92 or better(868/915 MHz bands)		−101 (at 40 kbps)	≤−70(required)	
					−87 to −93 (typical)	−90(typical)
	Transmit power (dBm)	−32 to 0		−20 to 0	−20 to 10	20/4/0(Class 1/2/3)
Link layer	MAC mecha-nism	TDMA+CSMA/CA (beacon mode) and CSMA/CA (beaconless mode)		CSMA/CA	TDMA	TDMA
	Message size (bytes)	127 (maximum)		64 (max. MAC payload in 200 series chip)	8 to 47	358 (maximum)
	Error control	16-bit CRC. ACKs (optional)		8-bit checksum. ACKs (optional)	24-bit CRC. ACKs	8-bit CRC (header); 16-bit CRC and 2/3 FEC (payload). ACKs
	Latency (ms)	<5 (beaconless mode, at 250 kbps)		<39 (at 40 kbps)	<3	<100
Identifiers		16- and 64-bit MAC addresses. 16-bit NWK identifiers	16- and 64-bit MAC addresses. 128-bit IPv6 addresses	32-bit (home ID), 8-bit (node ID)	48-bit public device Bluetooth address or random address	48-bit public device Bluetooth address
Device types or roles		Coordinator, Router and End device	Edge Router, Mesh Node (mesh under), Router (route over), Host	Controller and slave	Master and slave	Master and slave
Network layer	Multi-hop solution	Mesh routing, tree routing, and source routing	RPL (other protocols are not excluded)	Source routing	Not currently supported	Scatternet (routing protocol out of the scope of the Bluetooth specifications)
	Hop limit	30/10/5 (mesh routing/tree routing/source routing)	255	4	1	Outside scope of Bluetooth specifications
Security		Integrity, confidentiality, access control (IEEE 802.15.4 security, using 128-bit AES)		128-bit AES encryption (400 series chip)	Security Modes/Levels. Pairing. Key Gener./Distribution. Confidentiality, Authentication, and Integrity	Pairing and Link Key Generation. Authentication. Confidentiality. Trust Levels, Service Levels, and Authorization. E_X algorithms
		Key management	Key management currently out of scope			
Implementation size		45–128 kB (ROM), 2.7–12 kB (RAM)	24 kB (ROM), 3.6 kB (RAM)	32–64 kB (Flash), 2–16 kB (SRAM)	~40 kB (ROM), ~2.5 kB (RAM)	~100 kB (ROM), ~30 kB (RAM)

ZigBee, 6LowPAN

		ZigBee	6LoWPAN (Over 802.15.4)
Physical layer	RF band (MHz)	868/915/2400	
	Bit rate (kbps)	20/40/250	
	Modulation	BPSK/BPSK/O-QPSK	
	Spreading technique	DSSS	
	Receiver sensitivity (dBm)	−85 or better(2.4 GHz band)−92 or better(868/915 MHz bands)	
	Transmit power (dBm)	−32 to 0	
Link layer	MAC mecha-nism	TDMA+CSMA/CA (beacon mode) and CSMA/CA (beaconless mode)	
	Message size (bytes)	127 (maximum)	
	Error control	16-bit CRC. ACKs (optional)	
	Latency (ms)	<5 (beaconless mode, at 250 kbps)	

ZigBee, 6LowPAN

Identifiers		16- and 64-bit MAC addresses. 16-bit NWK identifiers	16- and 64-bit MAC addresses. 128-bit IPv6 addresses
Device types or roles		Coordinator, Router and End device	Edge Router, Mesh Node (mesh under), Router (route over), Host
Network layer	**Multi-hop solution**	Mesh routing, tree routing, and source routing	RPL (other protocols are not excluded)
	Hop limit	30/10/5 (mesh routing/tree routing/source routing)	255
Security		Integrity, confidentiality, access control (IEEE 802.15.4 security, using 128-bit AES)	
		Key management	Key management currently out of scope
Implementation size		45–128 kB (ROM), 2.7–12 kB (RAM)	24 kB (ROM), 3.6 kB (RAM)

Z-Wave

		Z-Wave
Physical layer	RF band (MHz)	868/908 (all chips) 2400 (400 serie chip)
	Bit rate (kbps)	9.6/40 (from 200 series chip) 200 (only 400 series chip)
	Modulation	BFSK
	Spreading technique	No
	Receiver sensitivity (dBm)	−101 (at 40 kbps)
	Transmit power (dBm)	−20 to 0
Link layer	MAC mecha-nism	CSMA/CA
	Message size (bytes)	64 (max. MAC payload in 200 series chip)
	Error control	8-bit checksum. ACKs (optional)
	Latency (ms)	<39 (at 40 kbps)

Z-Wave

Identifiers		32-bit (home ID), 8-bit (node ID)
Device types or roles		Controller and slave
Network layer	**Multi-hop solution**	Source routing
	Hop limit	4
Security		128-bit AES encryption (400 series chip)
Implementation size		32–64 kB (Flash), 2–16 kB (SRAM)

Bluetooth Low Energy, Classic Bluetooth

		Bluetooth Low Energy	Classic Bluetooth
Physical layer	RF band (MHz)	2400	2400
	Bit rate (kbps)	1000	≤721(v1.2), 3000 (v2+EDR), ≤24,000 (v3+HS)
	Modulation	GFSK	GFSK (v1.2), GFSK/π/4-DQPSK/8DPSK (v2+EDR), 802.11 (v3+HS)
	Spreading technique	FHSS (2 MHz channel width)	FHSS(1 MHz channel width)
	Receiver sensitivity (dBm)	≤−70(required)	
		−87 to −93 (typical)	−90(typical)
	Transmit power (dBm)	−20 to 10	20/4/0(Class 1/2/3)
Link layer	MAC mecha-nism	TDMA	TDMA
	Message size (bytes)	8 to 47	358 (maximum)
	Error control	24-bit CRC. ACKs	8-bit CRC (header); 16-bit CRC and 2/3 FEC (payload). ACKs
	Latency (ms)	<3	<100

Bluetooth Low Energy, Classic Bluetooth

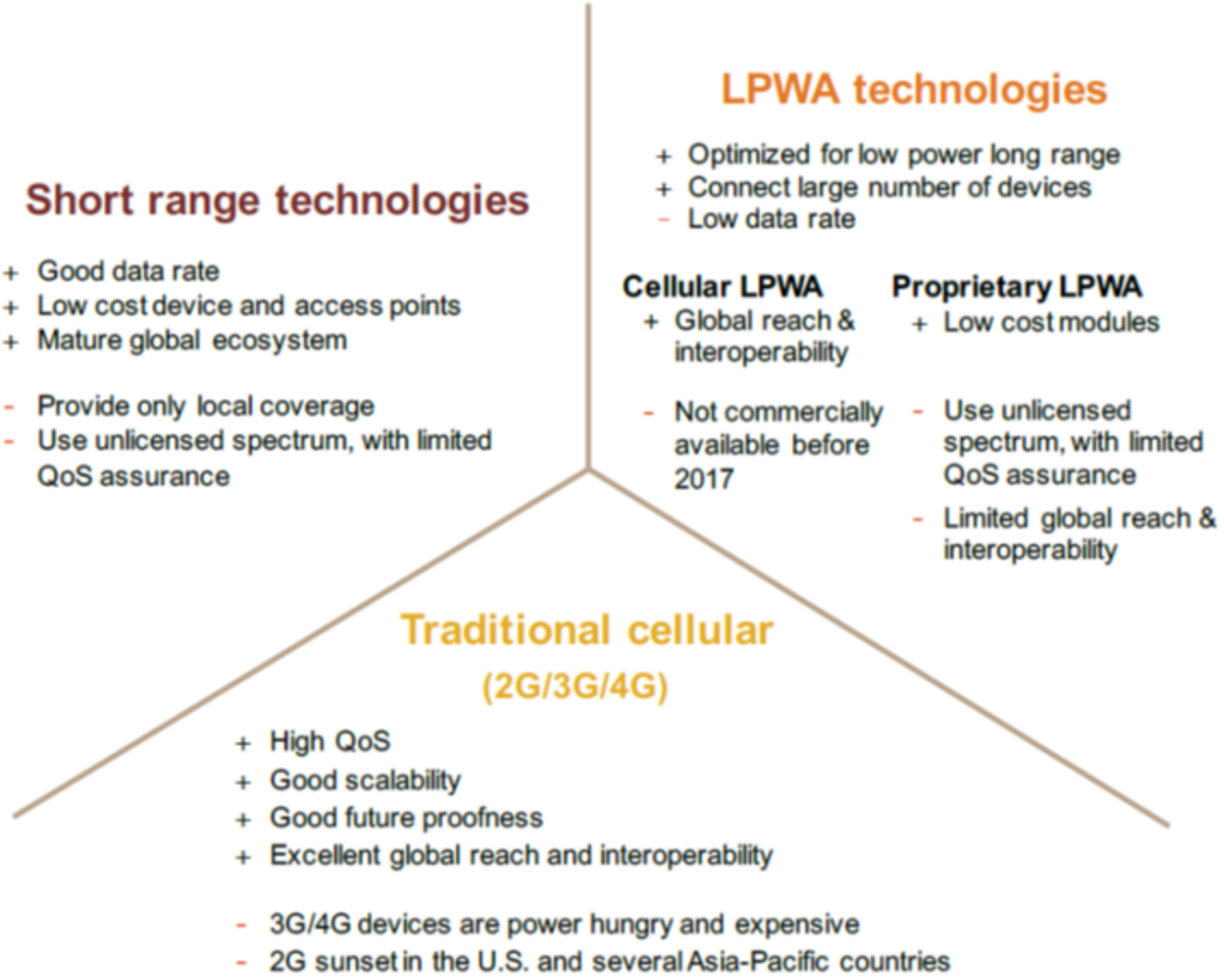
Identifiers		48-bit public device Bluetooth address or random address	48-bit public device Bluetooth address
Device types or roles		Master and slave	Master and slave
Network layer	**Multi-hop solution**	Not currently supported	Scatternet (routing protocol out of the scope of the Bluetooth specifications)
	Hop limit	1	Outside scope of Bluetooth specifications
Security		Security Modes/Levels. Pairing. Key Gener./Distribution. Confidentiality, Authentication, and Integrity	Pairing and Link Key Generation. Authentication. Confidentiality. Trust Levels, Service Levels, and Authorization. E_x algorithms
Implementation size		~40 kB (ROM), ~2.5 kB (RAM)	~100 kB (ROM), ~30 kB (RAM)

Near Field Communication (NFC)

	Near field communication
Frequency	13.56 MHz
Data rate	424 kbps
Communication range	<10 cm
Energy consumption (send, receive)	<15 mA

Selection of Suitable Technique for a planned IoT Application

Key Strengths and Weaknesses of Different Types of Connectivity Technologies

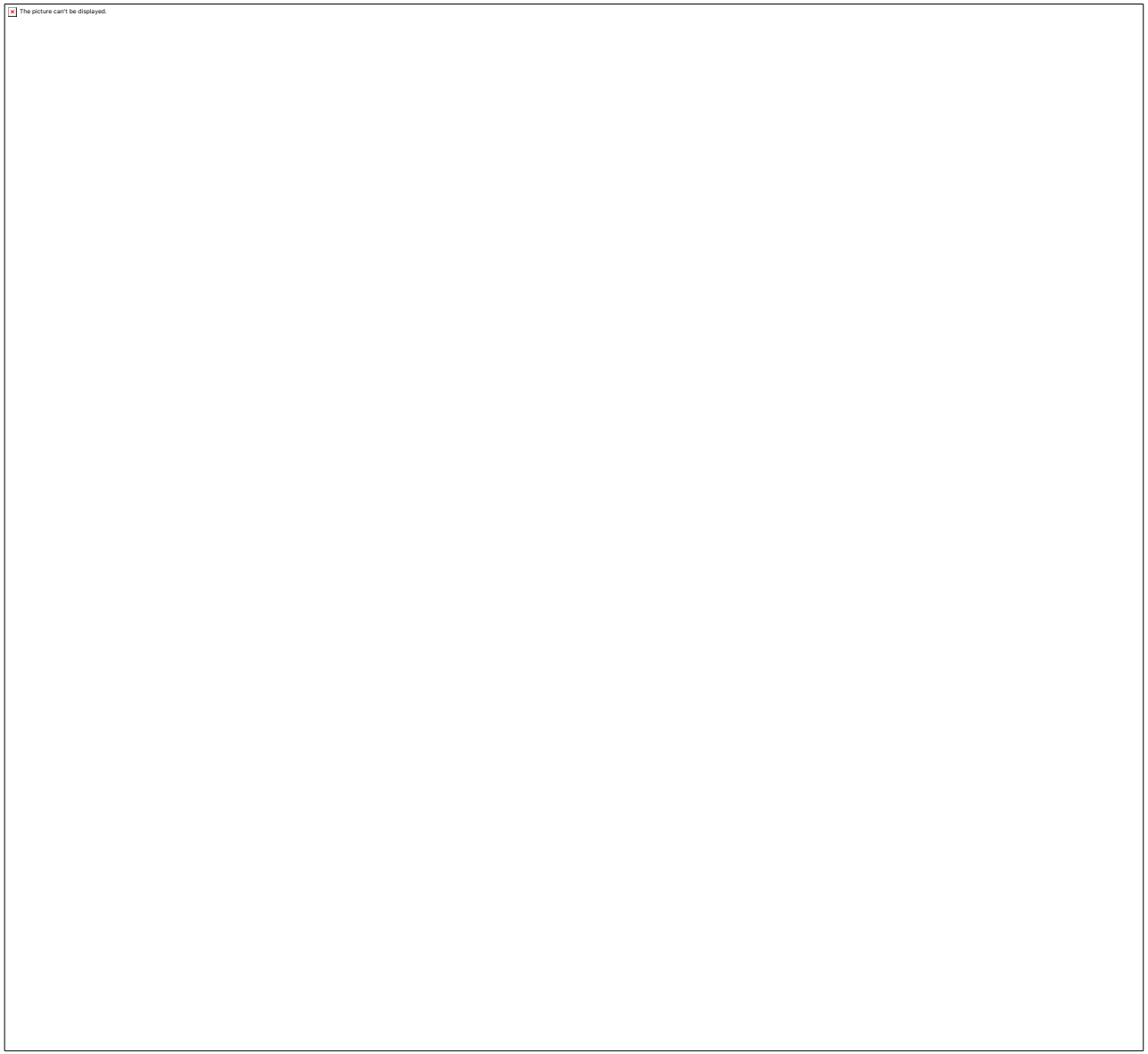


Src Telenor Connexion, 2016

Design Constraints on the Technical Level: Data Rate vs Coverage

SRC: LG

Design Constraints on the Technical Level: Data Rate vs Coverage vs Energy Consumption

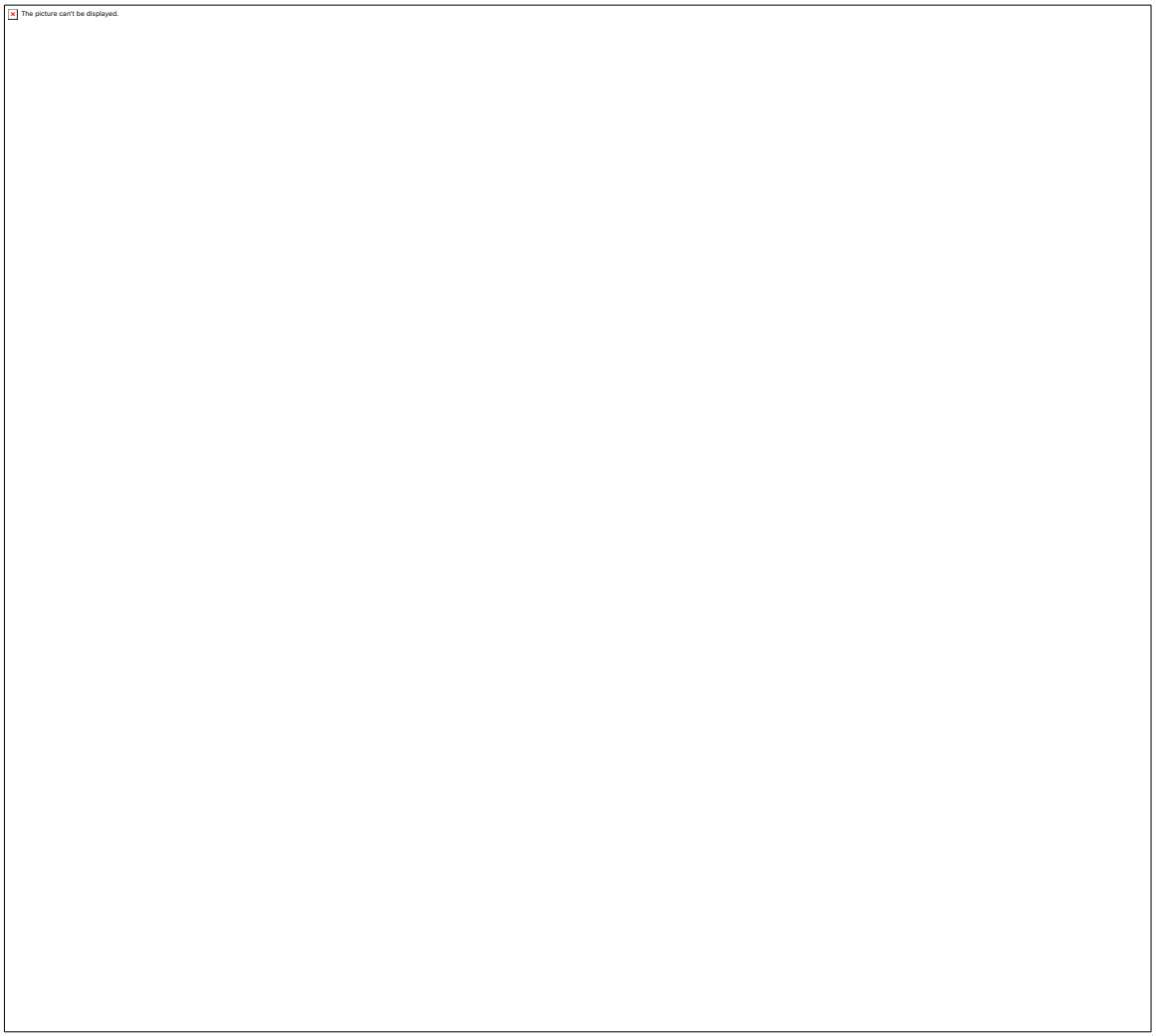


Src Telenor Connexion, 2016

Trade-offs on the Commercial Level: QoS vs Scalability vs. Cost

Main cost components of an IoT Device

- Connectivity module
- Sensors
- Battery
- Processor



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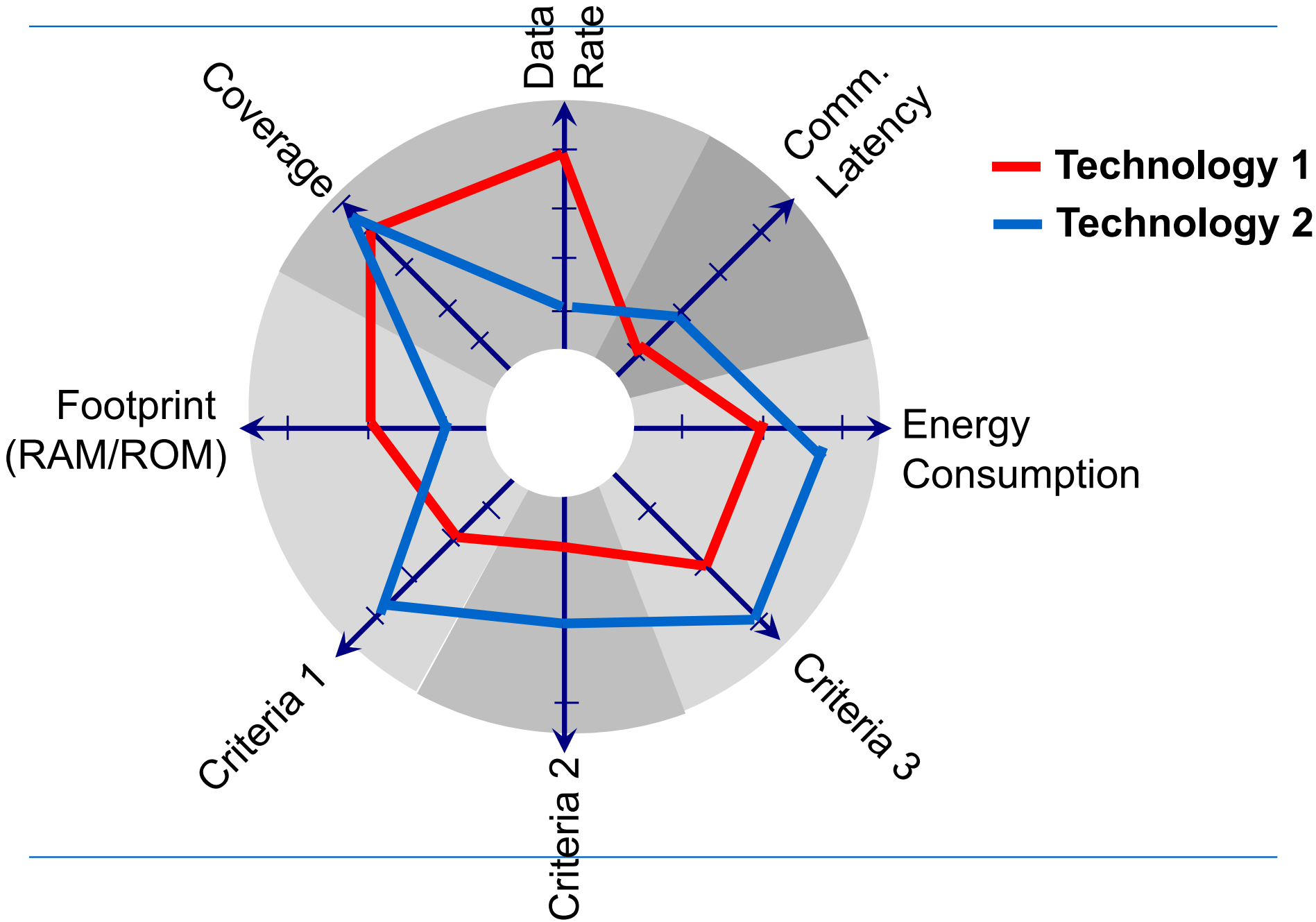
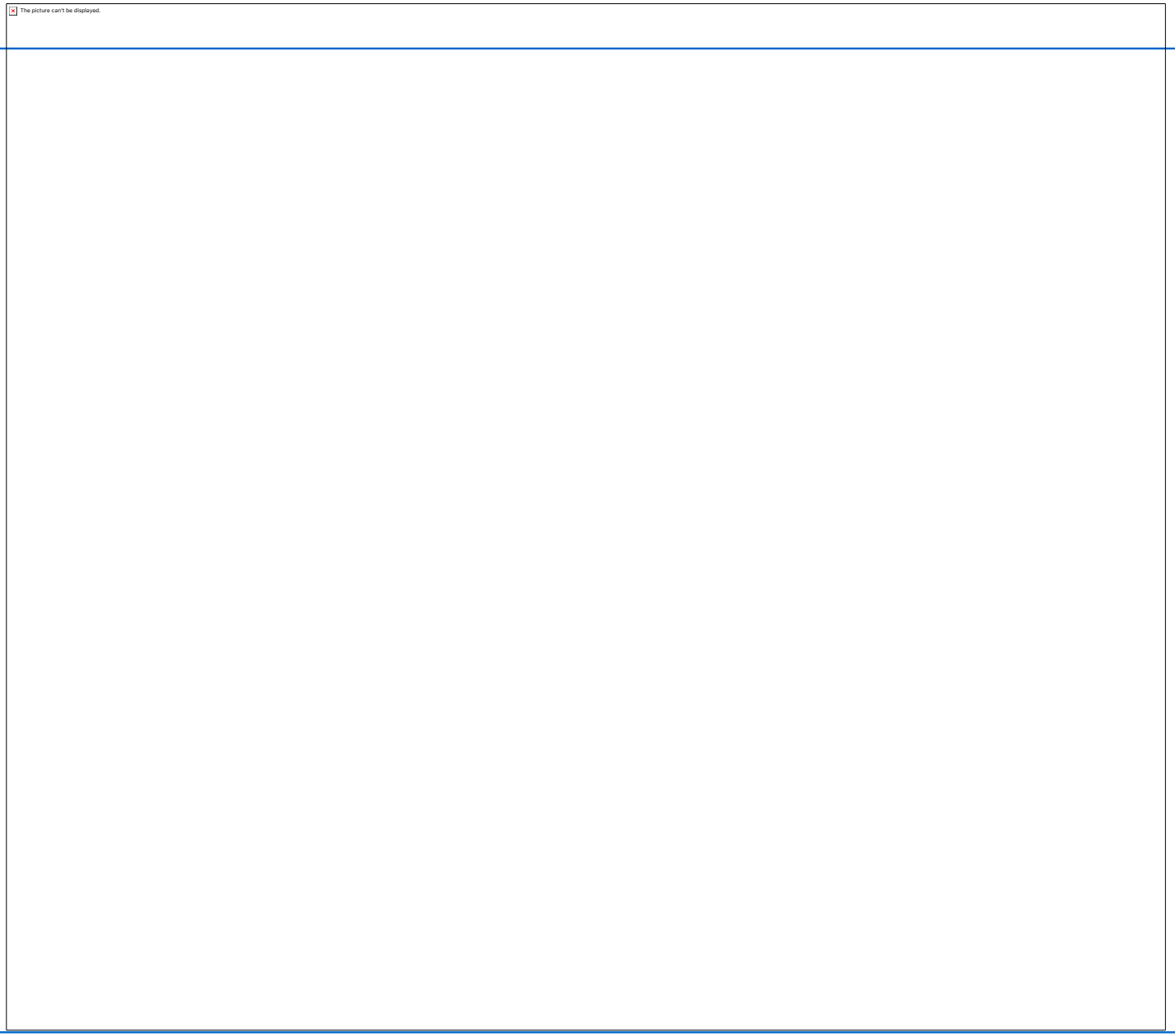
Spider Diagrams

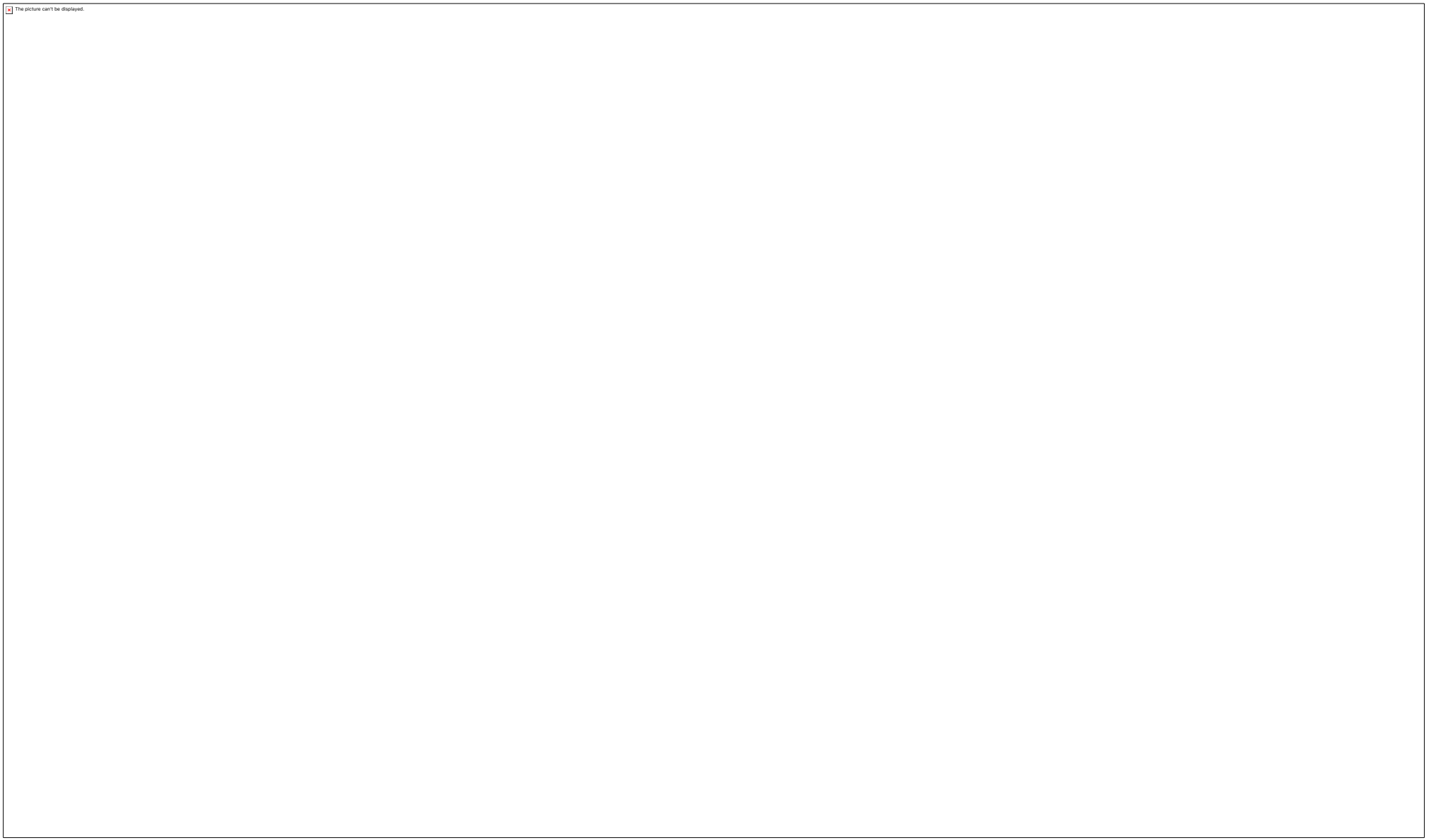


Characteristics of Wireless Networks (1)

Characteristics of Wireless Networks (2)



Suitability for Application Areas



Takeaways

- Rich landscape of technologies
- Selection of one or more technologies is a fundamental decision for the realization of an IoT application