Introduction to cellular IoT

Petter Myhre

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Today's host

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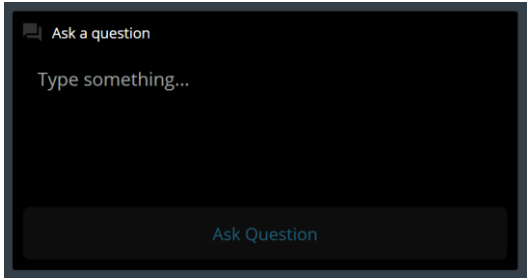
Practicalities

- Duration: 50-60 min
- Questions are encouraged!
- Please type questions in the top of the right sidebar
  - All questions are anonymous
  - Try to keep them relevant to the topic
- I will answer questions towards the end
- The chat is not anonymous, and should **not** be used for questions
- If you have more questions please use DevZone
- A recording of the webinar will be available together with the presentation at webinars.nordicsemi.com



DevZone

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Content

- What is cellular IoT?
- What is LTE?
- LPWAN landscape
- Getting connected to the network
- SIM cards
- Power consumption
- How distance affects protocol behavior

What is cellular IoT?

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New low power LTE technologies

	LTE-M	NB-IoT
Also known as	eMTC, LTE CAT-M1	LTE CAT-NB1
Bandwidth	1.4 MHz	200 kHz
Max throughput (DL/UL)	300/375 kbps	30/60 kbps
Range	<11 km	<15 km
Mobility	Yes	Yes
Roaming	Yes	Not yet
Battery lifetime	15 years	

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LTE-M and NB-IoT strengths

LTE-M strengths

- Higher throughput
- Lower latency
- Roaming
- Most power efficient at medium data rates
- Suitable for TCP/TLS end-to-end secure connection

NB-IoT strengths

- Longer range
- Better penetration
- Most power efficient at low data rates

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Typical LTE-M applications

Asset tracking

Wearables/Medical

Retail and POS

Home security

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Typical NB-IoT applications

Smart metering

Smart agriculture

Smart city

Predictive maintenance

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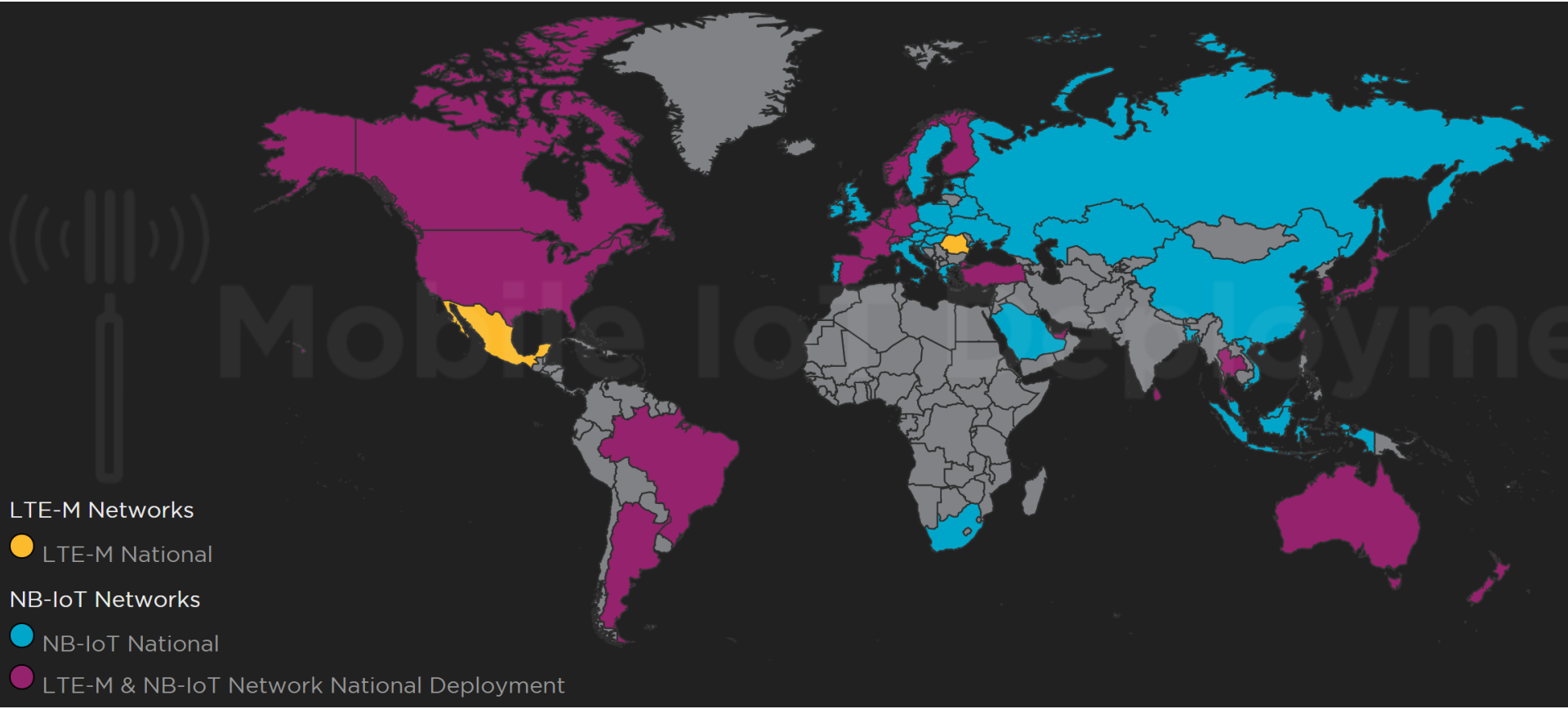

Source: www.gsma.com/iot/deployment-map/ April 2020

What is LTE?

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What is LTE?

- Cellular standard
- LTE – Long Term Evolution
- Also called 4G
- Maximize BW utilization
- Up to 300 Mbps
- Purely packet based

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3GPP

A GLOBAL INITIATIVE

- 3rd Generation Partnership Project
- Develop and maintain cellular standards
  - Including LTE
- Standards are structured as releases
  - Currently network support for Rel-13
  - Rel-14 is rolling out
  - Rel-15 (5G) in early adoption

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LTE products are split in Categories (Cat)

Cat 4	150 Mbps DL, 50 Mbps UL
Cat 3	100 Mbps DL, 50 Mbps UL
Cat 2	10 Mbps DL, 5 Mbps UL
Cat 1	1 Mbps DL, 1 Mbps UL
Cat	M1: 300 kbps DL and 375 kbps UL (technology NB1: 30 kbps DL and 60 kbps UL (M2 in Rel-14, NB2 in Rel-14)

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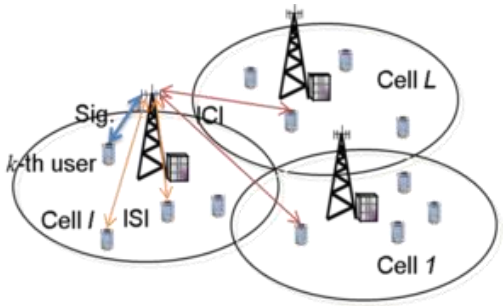
Terminology



- Star networks
  - eNB – (evolved Node B) - base stations in LTE
  - UE – user equipment - devices in LTE network
  - UL/DL – Uplink/Downlink
- Bandwidth and efficiency
  - FDD – Frequency division duplex - different frequency for UL/DL
  - TDD – Time division duplex - same frequency UL/DL time slots
  - MIMO – Multiple Input Multiple Output
  - HD/FD – Half Duplex/Full Duplex
- Mobile network operator (MNO)
  - Same as carrier

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LTE bands

- 56 LTE bands
- From 400 MHz – 6 GHz
- Some use FDD
- Some use TDD
- Different bands are licensed by different MNOs around the world

Band	Duplex mode	Uplink[A 1] (MHz)	Downlink[A 2] (MHz)
1	FDD	1920 – 1980	2110 – 2170
2	FDD	1850 – 1910	1930 – 1990
3	FDD	1710 – 1785	1805 – 1880
4	FDD	1710 – 1755	2110 – 2155
5	FDD	824 – 849	869 – 894
7	FDD	2500 – 2570	2620 – 2690
8	FDD	880 – 915	925 – 960
10	FDD	1710 – 1770	2110 – 2170
11	FDD	1427.9 – 1447.9	1475.9 – 1495.9
12	FDD	699 – 716	729 – 746
13	FDD	777 – 787	746 – 756
14	FDD	788 – 798	758 – 768
17	FDD	704 – 716	734 – 746
18	FDD	815 – 830	860 – 875
19	FDD	830 – 845	875 – 890
20	FDD	832 – 862	791 – 821
21	FDD	1447.9 – 1462.9	1495.9 – 1510.9
22	FDD	3410 – 3490	3510 – 3590
24	FDD	1626.5 – 1660.5	1525 – 1559
25	FDD	1850 – 1915	1930 – 1995
26	FDD	814 – 849	859 – 894
27	FDD	807 – 824	852 – 869
28	FDD	703 – 748	758 – 803
30	FDD	2305 – 2315	2350 – 2360
31	FDD	452.5 – 457.5	462.5 – 467.5
65	FDD	1920 – 2010	2110 – 2200
66	FDD	1710 – 1780	2110 – 2200[2]
68	FDD	698 – 728	753 – 783
70	FDD	1695 – 1710	1995 – 2020
71	FDD	663 – 698	617 – 652
72	FDD	451 – 456	461 – 466
73	FDD	450 – 455	460 – 465
74	FDD	1427 – 1470	1475 – 1518
85	FDD	698 – 716	728 – 746

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LTE bands – How to products manage?

- All run subsets of bands
- Smartphones support many bands, but not all,
  - iPhone supports 28 bands
- Traditional LTE modules 1 – 5 bands
  - Geographic or MNO specific

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LTE bands – cellular IoT

- Lower frequencies provides longer range
  - Bands 12 and 13 (4) are most common US
  - Bands 8, 20, 28 (3) are most common in EUR/APAC
- Half duplex operation opens for much simpler multiband support
  - Enable UE to operate in larger regions
- nRF9160 is currently certified for 17 bands, and more is coming
  - Global coverage

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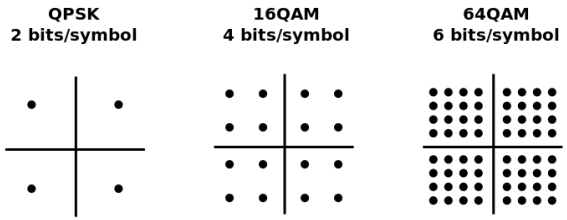
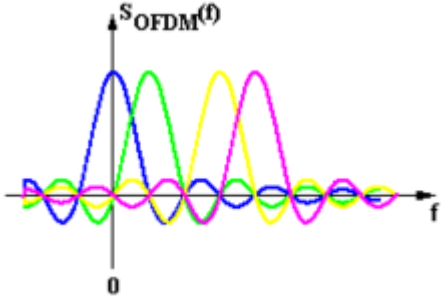
LTE bandwidth





- Dynamic modulation
  - BPSK, QPSK, 16QAM, 64QAM
  - Changes depending on signal quality
  - Can be different for UL and DL
  - Dictated by eNB
- Orthogonal frequency-division multiplexing (OFDM)
  - Up to 1200 subcarriers, 15 kHz appart
- MIMO
- Full duplex in FDD

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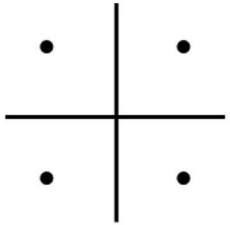
LTE bandwidth – cellular IoT

- LTE-M
  - Less bandwidth (1.4 MHz)
  - No 64QAM
  - No MIMO
  - Less OFDM subcarriers (72)
  - Can use half duplex

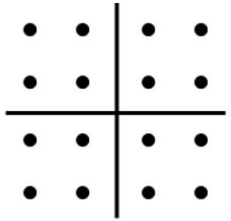
QPSK

2 bits/symbol



16QAM

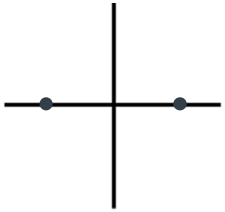
4 bits/symbol



- NB-IoT
  - Less bandwidth (200 kHz)
  - No 64QAM or 16QAM
  - No MIMO
  - OFDM subcarriers (12)
  - Must use half duplex

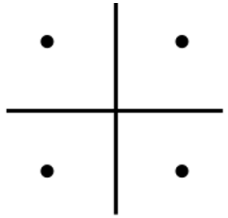
BPSK

1 bit/symbol



QPSK

2 bits/symbol



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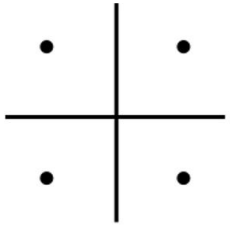
LTE bandwidth – cellular IoT

- LTE-M
  - QPSK or 16QAM in both UL and DL depending on signal quality
- NB-IoT
  - BPSK or QPSK in UL depending on signal quality
  - Only QPSK in DL

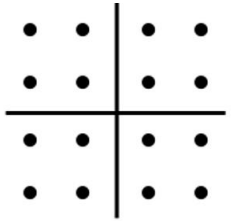
QPSK

2 bits/symbol



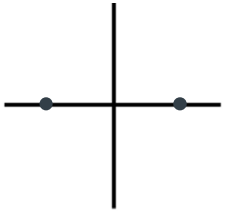
16QAM

4 bits/symbol



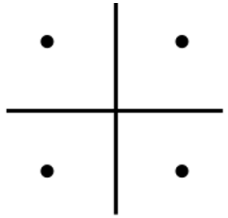
BPSK

1 bit/symbol



QPSK

2 bits/symbol



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Certifications

MNO

Separate certification for LTE-M and NB-IoT

Regulatory standards

Regional certification

3GPP

3GPP compliance

Full overview and roadmap on nordicsemi.com/9160cert

LPWAN landscape

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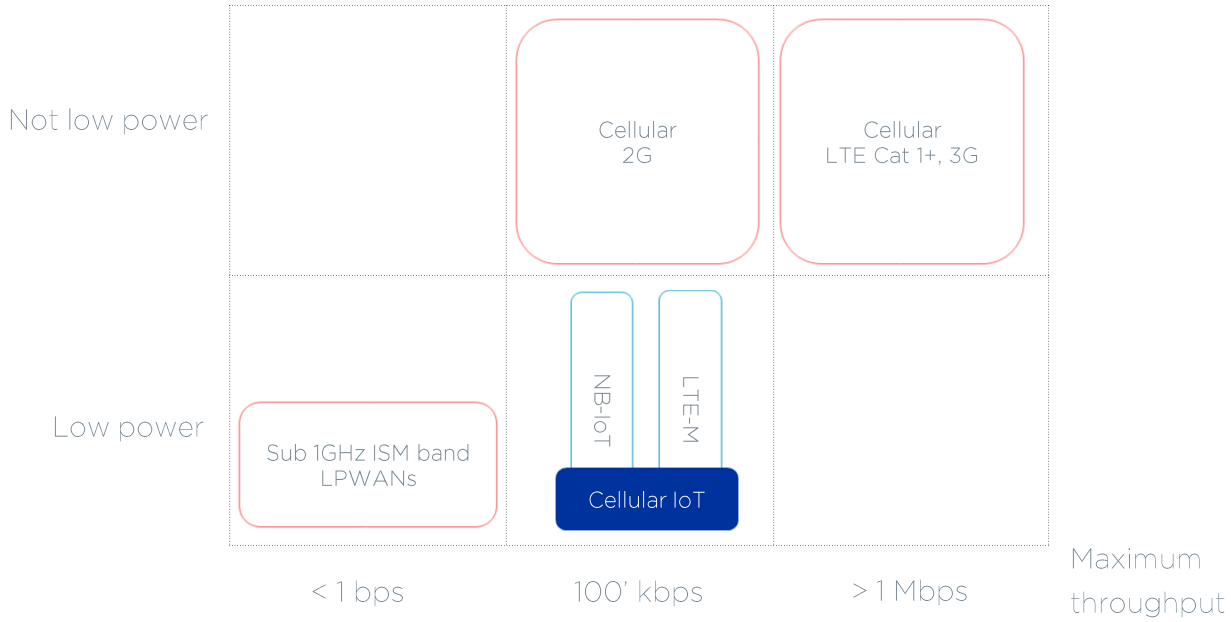
LPWAN technology landscape



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Cellular IoT advantages

- Open standard with large industry support
- Future proof
- Leverage existing infrastructure
- Global operation with roaming possibilities

3GPP™

A GLOBAL INITIATIVE

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Cellular IoT advantages

- Security is built into LTE
- TLS/DTLS support to secure data all the way to cloud
- Enough throughput to update firmware over-the-air

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Cellular IoT advantages

- Dedicated spectrum
  - Radio resources are managed
  - No interference
  - Full quality of service is supported
- Reliable and predictable performance
- Limited regulatory restrictions
- Extremely scalable
  - Up to 200 000 nodes per base station

Getting connected

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Getting connected - Attach

- eNB broadcasts master information blocks (MIB)
- UE finds best eNB through signal strength analysis
- UE sends attach request
- UE is authenticated using SIM data

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Getting connected - Attach

- eNB broadcasts master information blocks (MIB)
- UE finds best eNB through signal strength analysis
- UE sends attach requests
- UE is authenticated using SIM data
- Connection is established
- Data can be exchanged with the network

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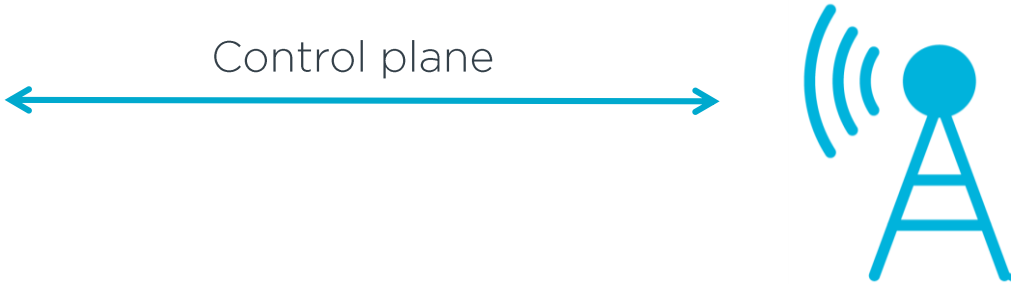
Exchanging data with the network

Control plane

- Intended for control traffic
- Typically used by NB-IoT

- Limited data traffic possible
  - Efficient for small pieces of data
  - 10-20 kbps
  - Suitable for UDP/DTLS
- Control traffic has priority



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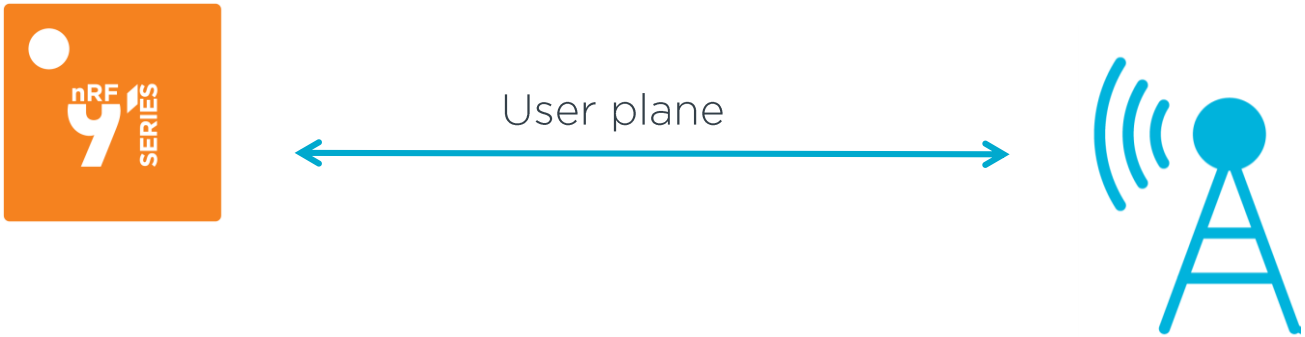
Exchanging data with the network

User plane

- Intended for data traffic
- Typically used by LTE-M
- Can be used by NB-IoT

- High data traffic possible
  - Efficient for larger pieces of data
  - 100's of kbps for LTE-M
  - Suitable for TCP/TLS and UDP/DTLS



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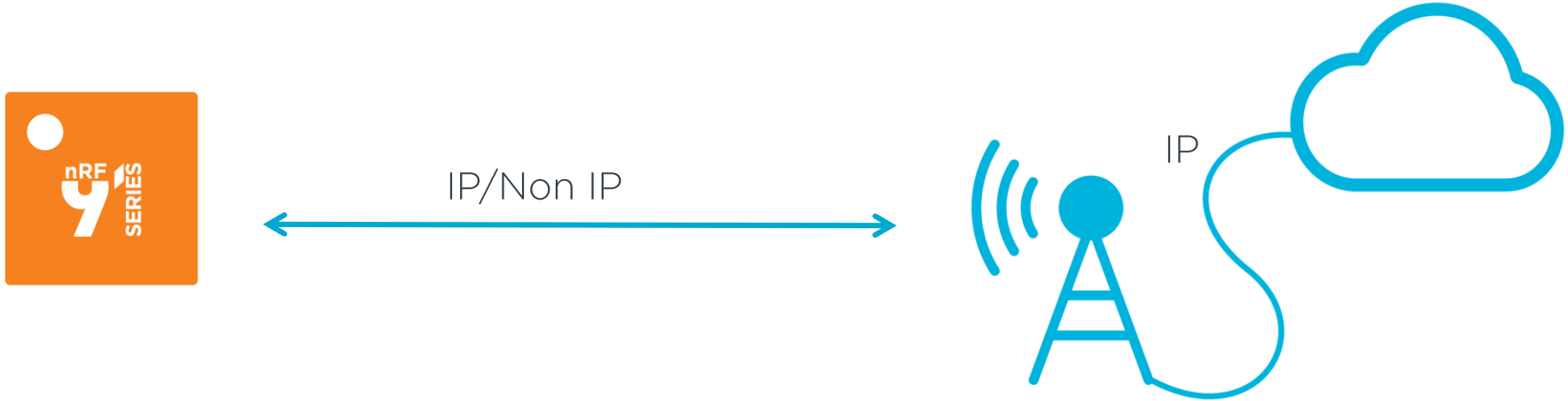
Exchanging data with the Cloud

IP/Non IP – Through Core Network

- Data to and from the Cloud is relayed by the Core Network
- Migrating to a new network is challenging
- Typically no roaming



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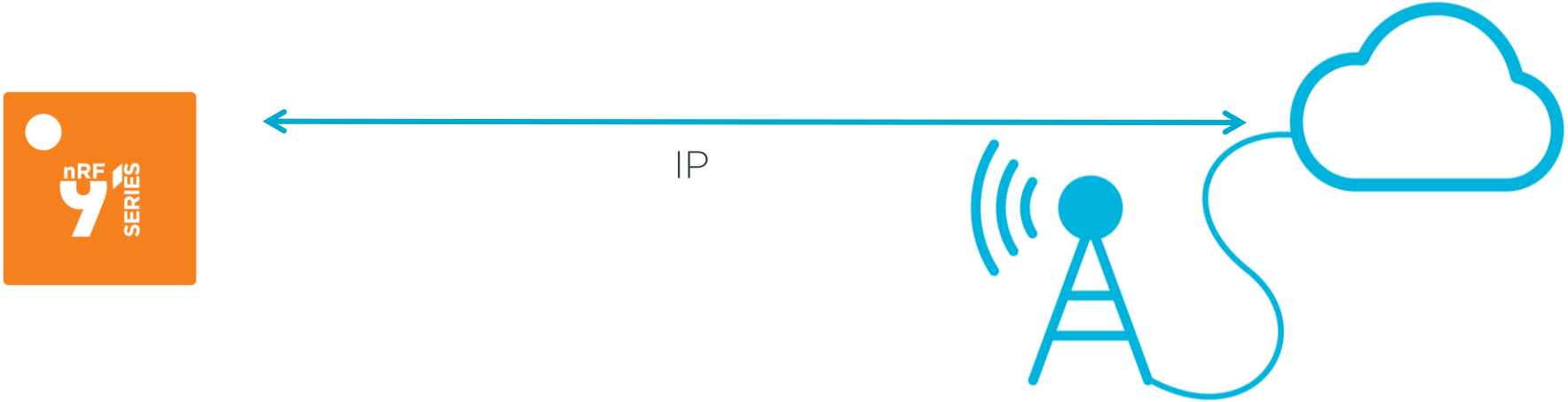
Exchanging data with the cloud

IP - Direct to the cloud

- End-to-end encryption and authentication
- Everything is independent, works with any network
- Roaming is possible



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Connection modes

RRC Connected

Transfer user data

High power consumption

RRC Idle

Sleep for shorter intervals to save power

Shorter DL latency

PSM

Sleep for longer intervals to save power

Longer DL latency

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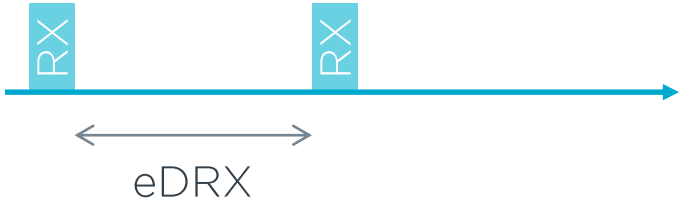
Connection modes - RRC Idle

- Extended Discontinuous Receive (eDRX)
- Sleep in eDRX intervals to save power
  - LTE-M: Up to ~44 min
  - NB-IoT: Up to ~175 min
- Listens (RX) at the end of each interval
- UE can wake up at any time to send data
- eNB stores data for UE
- Longer eDRX intervals results in longer DL latency, but lower power



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Connection modes - PSM

- Power saving mode
- Sleep in PSM intervals to save power
  - LTE-M/NB-IoT: 10 min to 413 days
- Must go to RRC Connected at the end of each interval
- UE can wake up at any time to send data
- eNB stores data for UE
- Longer PSM intervals results in longer DL latency, but lower power

SIM cards

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What is a SIM card

- A secure microcontroller
- It securely stores
  - Subscriber identity
  - Keys used to encrypt connection
- Different form factors
- Three main types
  - SIM
  - eSIM
  - iSIM

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SIM, eSIM, iSIM

SIM	eSIM	iSIM
Plug-in or solderable	Plug-in or solderable	Integrated
Locked to one MNO	User can change MNO	User can change MNO

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When selecting a cellular IoT SIM

- The SIM can drain much more current than the LTE modem itself
- Clock stop
  - Used when SIM is not active
  - 20-100 uA
- Power down
  - Used for longer sleep intervals (eDRX, PSM)
  - Restrictions on min. sleep interval
  - Check that SIM can power down often/many times

Power consumption

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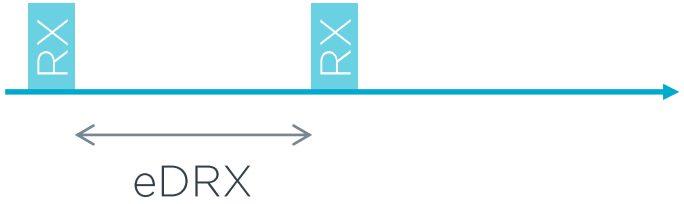
eDRX and PSM – essential for cellular IoT

- eDRX
- Cost less current to re-connect
- Higher floor current
  - nRF9160 eDRX floor current is 7 uA

- PSM
- Cost more current to re-connect
  - Except when it is already in RRC Connected
- Lower floor current
  - nRF9160 PSM floor current is 4 uA



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Power consumption – nRF9160 SiP

LTE-M: ~ 5 uA NB-IoT: ~7 uA	LTE-M: ~9 uA NB-IoT: ~20 uA	LTE-M: ~9 uA NB-IoT: ~11 uA	LTE-M: ~0.75 mA
PSM mode UL 1 KB every 12 hours 12 hour DL latency	PSM mode UL 100 B every 2 hours 2 hour DL latency	eDRX No UL data 10 min DL latency	GPS fix and UL of location data every 2.7 min (eDRX)

23 dBm, 3.7 V

How distance affects protocol behavior

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Parameters are dynamically changed

QPSK
High TX power

QPSK
High TX power

16QAM
High TX power

16QAM
Low TX power

- Output power and modulation are dynamically changed by eNB, depending on signal quality
- User equipment never uses more energy than necessary
- To learn more:
  - Watch **Field-testing how distance affects the behavior of LTE-M and NB-IoT** on our Youtube channel