# Sync in 5G and Fronthaul Networks

November 2018

**Tim Frost**

# What is 5G?

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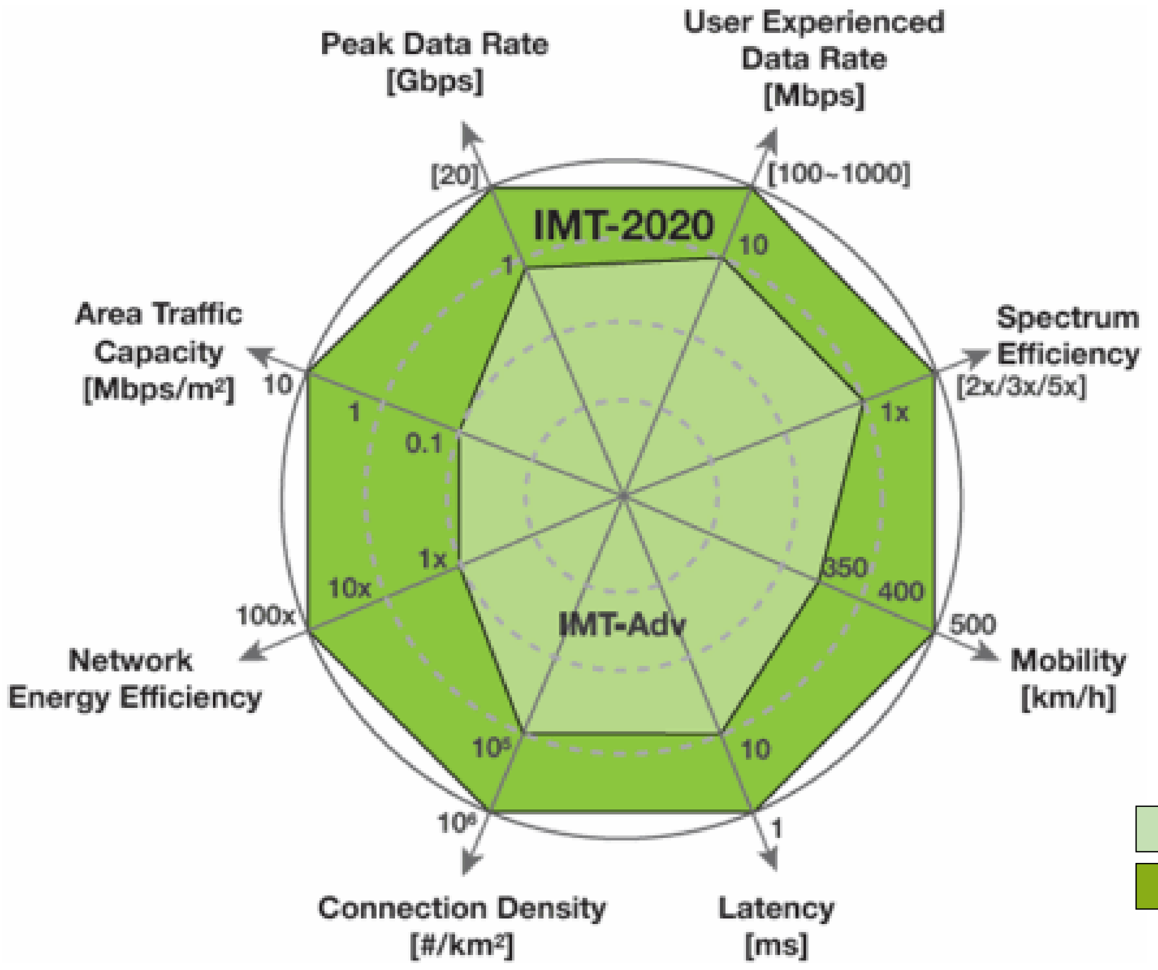
- *“A wireless infrastructure to connect the world” **
  - Enhanced mobile broadband
  - Ultra-reliable and low latency communication (URLLC)
  - Massive machine-to-machine type communications (i.e. the “internet of things”)
- Mobile Operators’ vision:
  - Anything better than the current offering that can be branded as “5G”
    - Current LTE-Advanced offering is just carrier aggregation, branded 4.5G in some markets
  - Quite likely that anything beyond Carrier Aggregation (CA) will be marketed as 5G
    - e.g. eICIC, CoMP, MBMS, MIMO
  - Starts with enhanced mobile broadband, IoT and URLLC will follow later



** From ITU-R M2083.0, “IMT Vision”*

# What is 5G?

- **IMT-2020** – the ITU's vision of "5G", to roll out in 2020




IMT-Advanced (LTE, 4G)

IMT-2020 (5G), relative to IMT-Advanced

# What are the implications?

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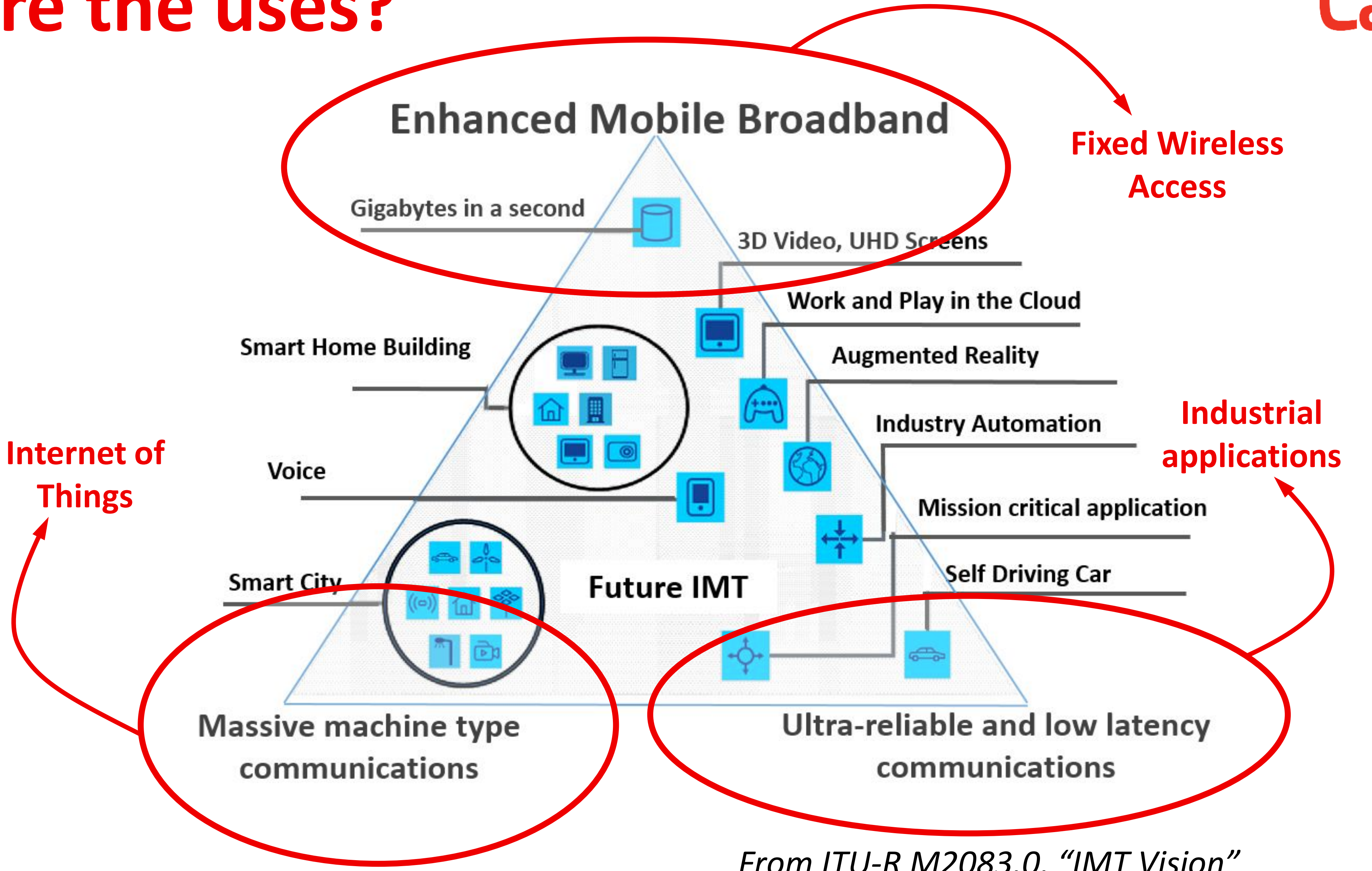
- Peak data rate of 20Gbit/s
  - eNodeB connections at least 25Gbit/s
  - Backhaul networks will require 100Gbit/s or more
- User experienced data rate of 100-1000Mbit/s
  - Co-operative processing and interference management
  - These techniques typically require very accurate synchronisation
- Connection density of 1M connections/$km^2$
  - Requires dense small cell or remote radio unit (RRU) deployment
  - Small, cheap RRU’s preferred due to the number of devices required
- Latency < 1ms
  - Distributed architecture, data processing and switching at the edge
  - Fronthaul architecture with distributed radio units and co-located baseband and switching in the core

# 5G Uses

# What are the uses?




*From ITU-R M2083.0, "IMT Vision"*

# Fixed Wireless Access

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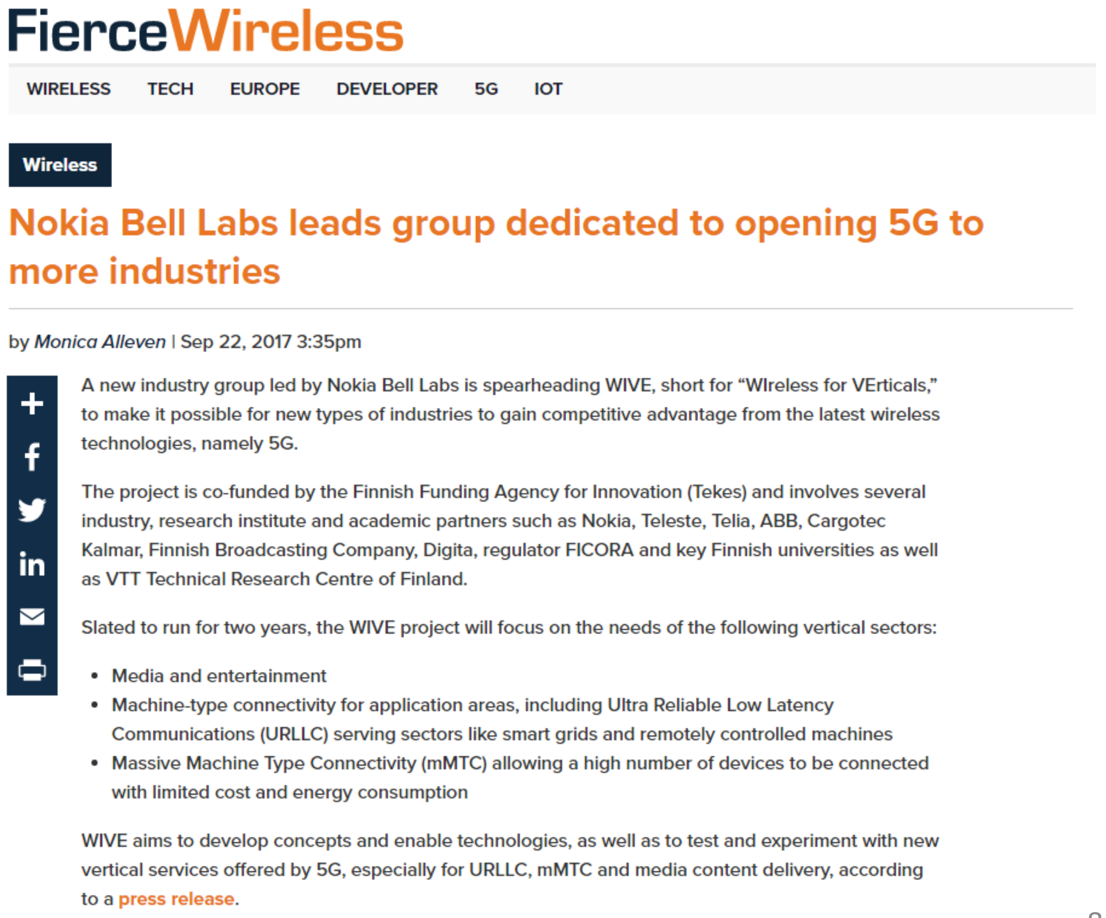
- 1Gbit/s to the handset? That’s 20x better than my home broadband…
- Major operators proposing to use 5G for fixed wireless access
  - Looking at the 28 or 39GHz bands (millimetre wave), 500m range
  - Principal target is dense urban environments, but some carriers investigating it for rural last mile
  - Estimated to be 40% cheaper deployment than FTTP*
  - $40B market by 2025*
- Another form of convergence
  - Home/office and mobile infrastructure merge
    - Cost savings for operators on infrastructure
    - More opportunities to compete with the incumbent supplier
  - Backhaul capacity will have to increase massively
    - Move to 100G and beyond accelerated

*SNS Research report: “5G for FWA: 2017 – 2030”

# Wireless Industrial Networks and IoT

- 5G aiming at unifying a wide range of hitherto diverse networks
- Examples:
  - Sensor networks for smart buildings, environmental monitoring
  - Smart cities and transport networks
  - Warehouse management and stock tracking
  - Automotive networks and autonomous vehicles
  - Healthcare and wearable devices
- Nokia Bell Labs set up "WIVE" (***WI***reless for ***VE***rticals) to study the impact of 5G on vertical markets


FierceWireless

WIRELESS TECH EUROPE DEVELOPER 5G IOT

Wireless

## Nokia Bell Labs leads group dedicated to opening 5G to more industries

by *Monica Alleven* | Sep 22, 2017 3:35pm

A new industry group led by Nokia Bell Labs is spearheading WIVE, short for "WIreless for VErticals," to make it possible for new types of industries to gain competitive advantage from the latest wireless technologies, namely 5G.

The project is co-funded by the Finnish Funding Agency for Innovation (Tekes) and involves several industry, research institute and academic partners such as Nokia, Teleste, Telia, ABB, Cargotec Kalmar, Finnish Broadcasting Company, Digita, regulator FICORA and key Finnish universities as well as VTT Technical Research Centre of Finland.

Slated to run for two years, the WIVE project will focus on the needs of the following vertical sectors:

- Media and entertainment
- Machine-type connectivity for application areas, including Ultra Reliable Low Latency Communications (URLLC) serving sectors like smart grids and remotely controlled machines
- Massive Machine Type Connectivity (mMTC) allowing a high number of devices to be connected with limited cost and energy consumption

WIVE aims to develop concepts and enable technologies, as well as to test and experiment with new vertical services offered by 5G, especially for URLLC, mMTC and media content delivery, according to a press release.

# Network Slicing

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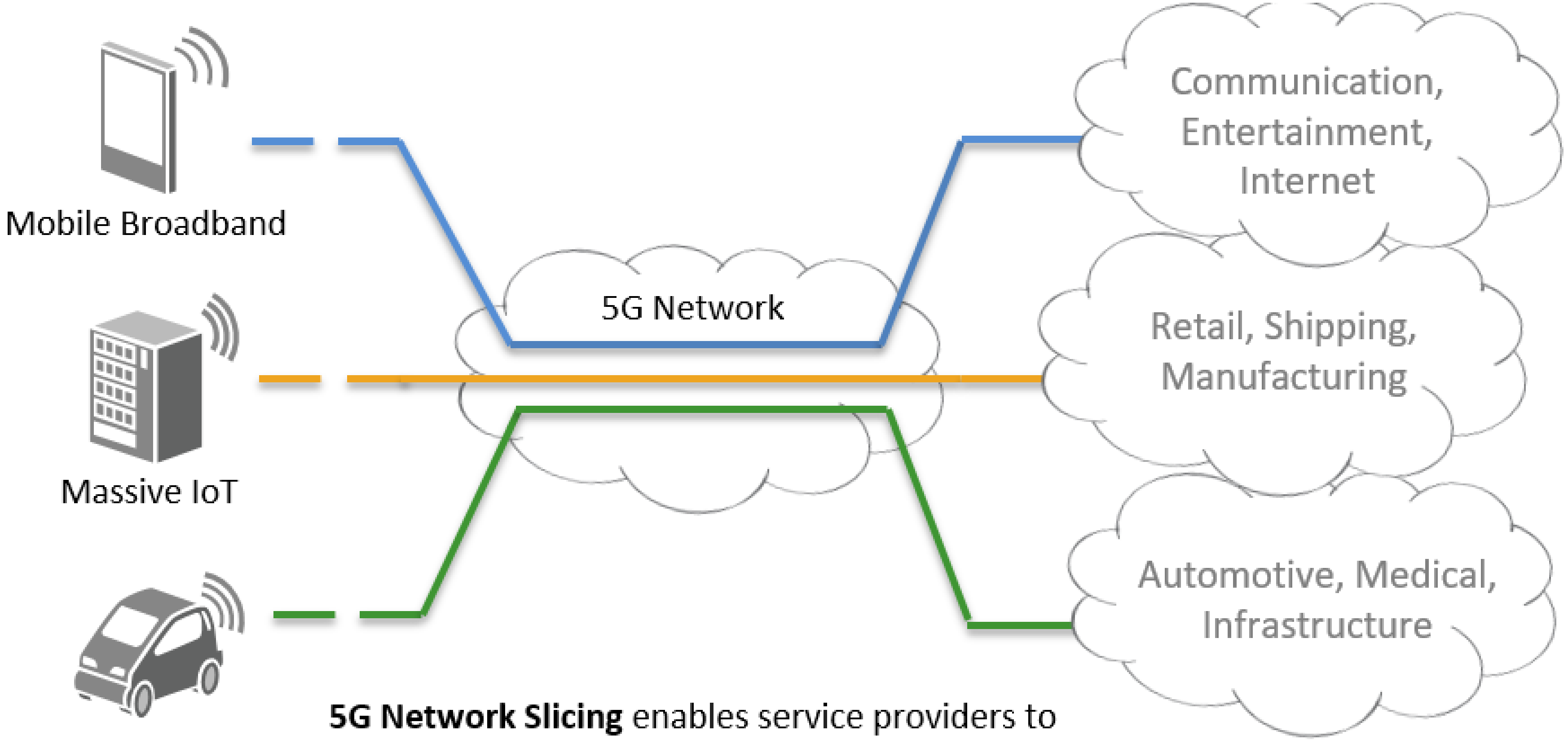
- Virtual networks created to meet the diverse demands of different applications




**5G Network Slicing** enables service providers to build end-to-end virtual networks tailored to application requirements.

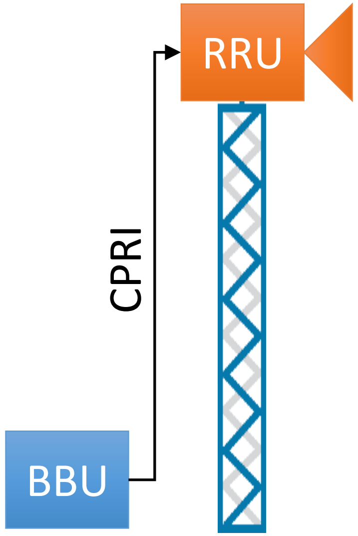


https://www.vanillaplus.com/2017/01/31/24983-network-slicing-unleashes-5g-opportunities-service-quality-can-assured-part-2/

# Fronthaul Networks

# What's going on?

- Fronthaul used to be simple and short:
  - Baseband unit (BBU) on cell site, remote radio unit (RRU) at top of mast
  - Used CPRI (Common Public Radio Interface) to carry radio signal over fibre up the mast to the radio unit
  - RRU modulates signal onto carrier and transmits
- Then operators started putting the baseband units further away
  - "Baseband hotel" concept – put all the BBUs for an area in a central location, and use CPRI to connect the RRUs
  - This is expensive as it requires dedicated fibre to each RRU
  - Use of shared networks was proposed, e.g. CPRI over Ethernet



# 5G "X-Haul" Networks

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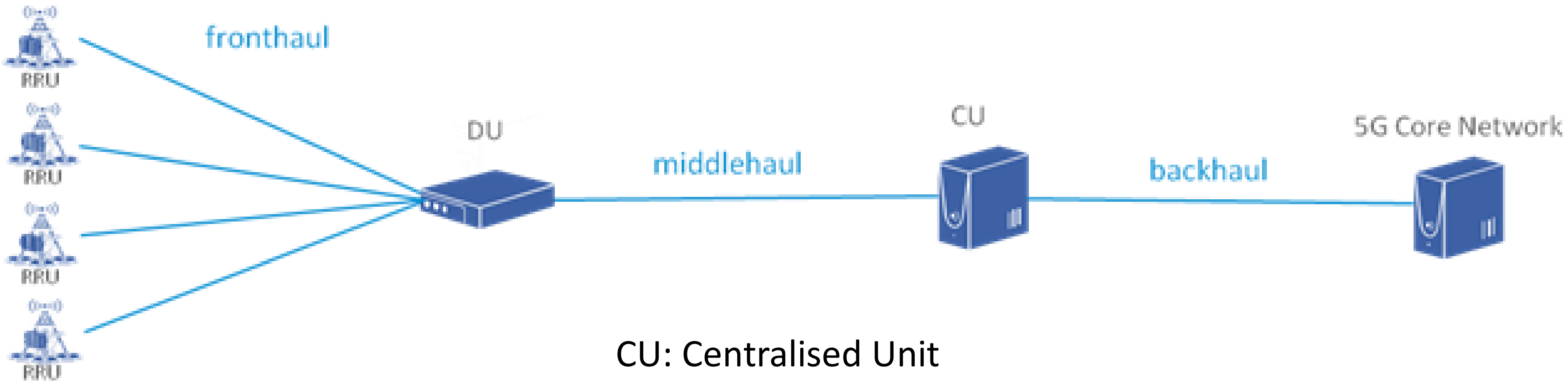
- 4G Fronthaul (e.g. CPRI) carries the radio signal over a dark fibre
  - Costly deployment, would be better to use shared network (e.g. Ethernet)
- Carrying a radio signal over a digital link is inefficient
  - Better to carry the actual data before modulating onto a radio signal
  - With 5G, it would be at least 25Gb/s to each radio unit
  - Proposed splitting the basestation (gNodeB) into three parts, fronthaul, middlehaul and backhaul:




CU: Centralised Unit
DU: Distributed Unit
RRU: Remote Radio Unit

# Frontthaul Protocols

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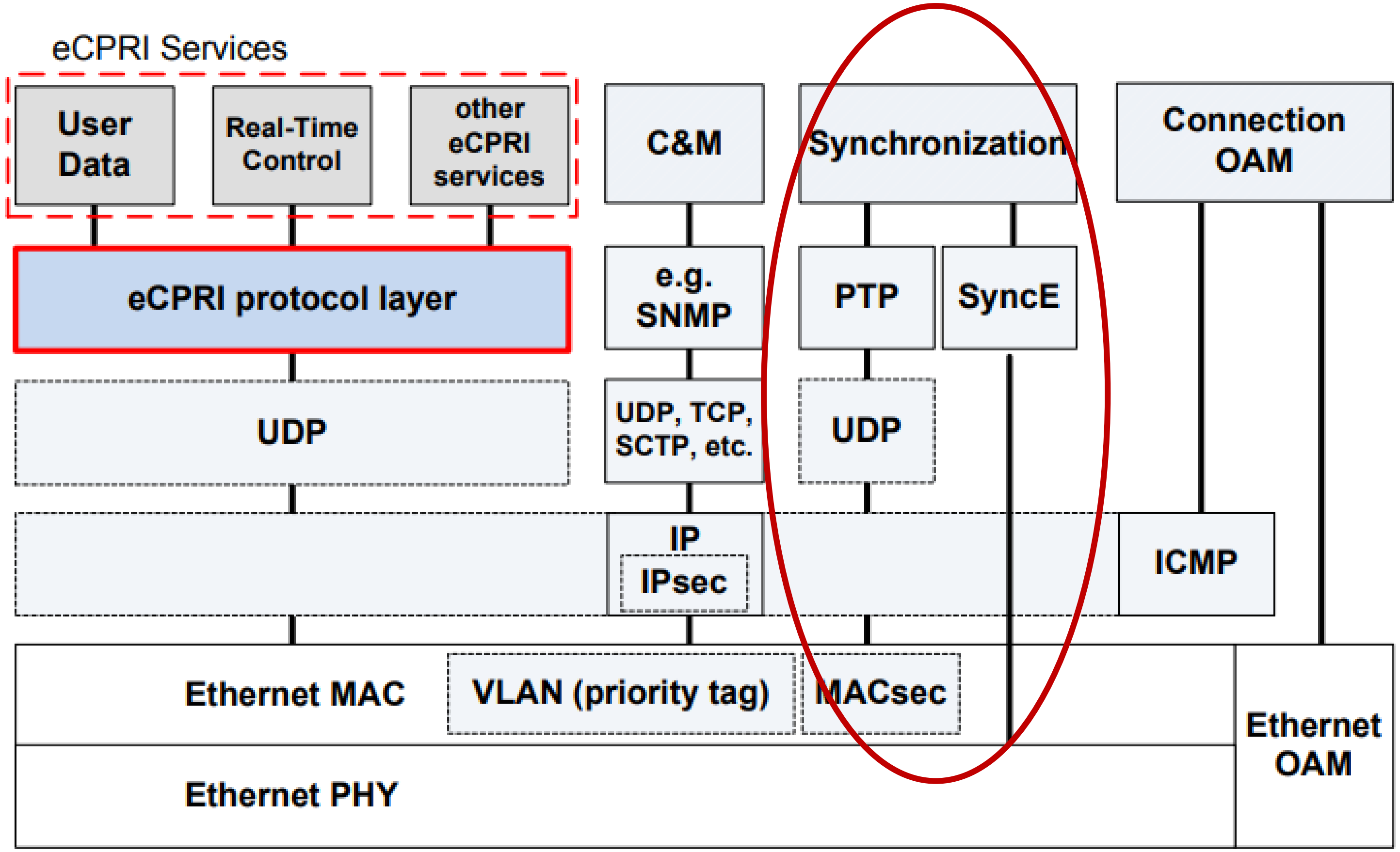
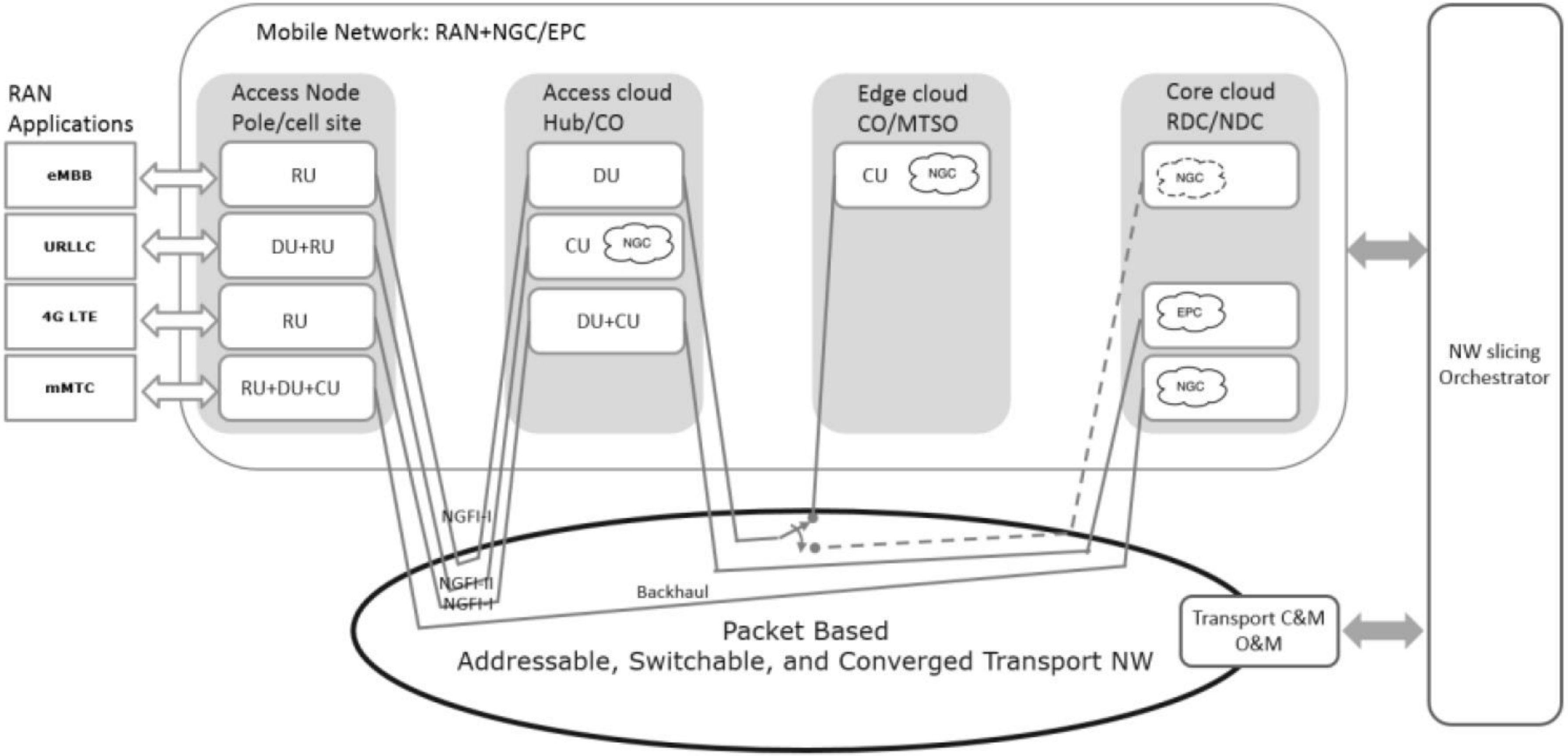
- CPRI version 7
  - Radio over dark fibre, data rates at 10 and 25 Gb/s
  - Produced by the CPRI partnership, www.cpri.info, (Ericsson, Huawei, NEC and Nokia)
- eCPRI
  - Protocol for Radio over Ethernet or IP networks
  - Defines different functional splits between eRE (radio equipment, eCPRI terminology for the RRU) and eREC (radio equipment controller, CU/DU equivalent)
- IEEE802.1CM
  - Time Sensitive Networking for Fronthaul
  - Broadly complementary to eCPRI, provides the synchronisation piece (sync is out of scope for eCPRI itself)
  - Based in turn on ITU-T G.8275 synchronisation architecture
- IEEE1914.3
  - Protocol for Radio over Ethernet
  - Open standards-based approach to fronthaul; clear competitor to eCPRI
- IEEE1914.1
  - Packet based Fronthaul Transport Networks
  - Defines the transport network requirements for IEEE1914.3, including synchronisation

# eCPRI: Frontahul over Ethernet




No details on sync: can be provided by multiple methods

# Network Slicing again…




From draft IEEE1914.1, "Packet-Based Fronthaul Transport Networks"

# Network Technology Options

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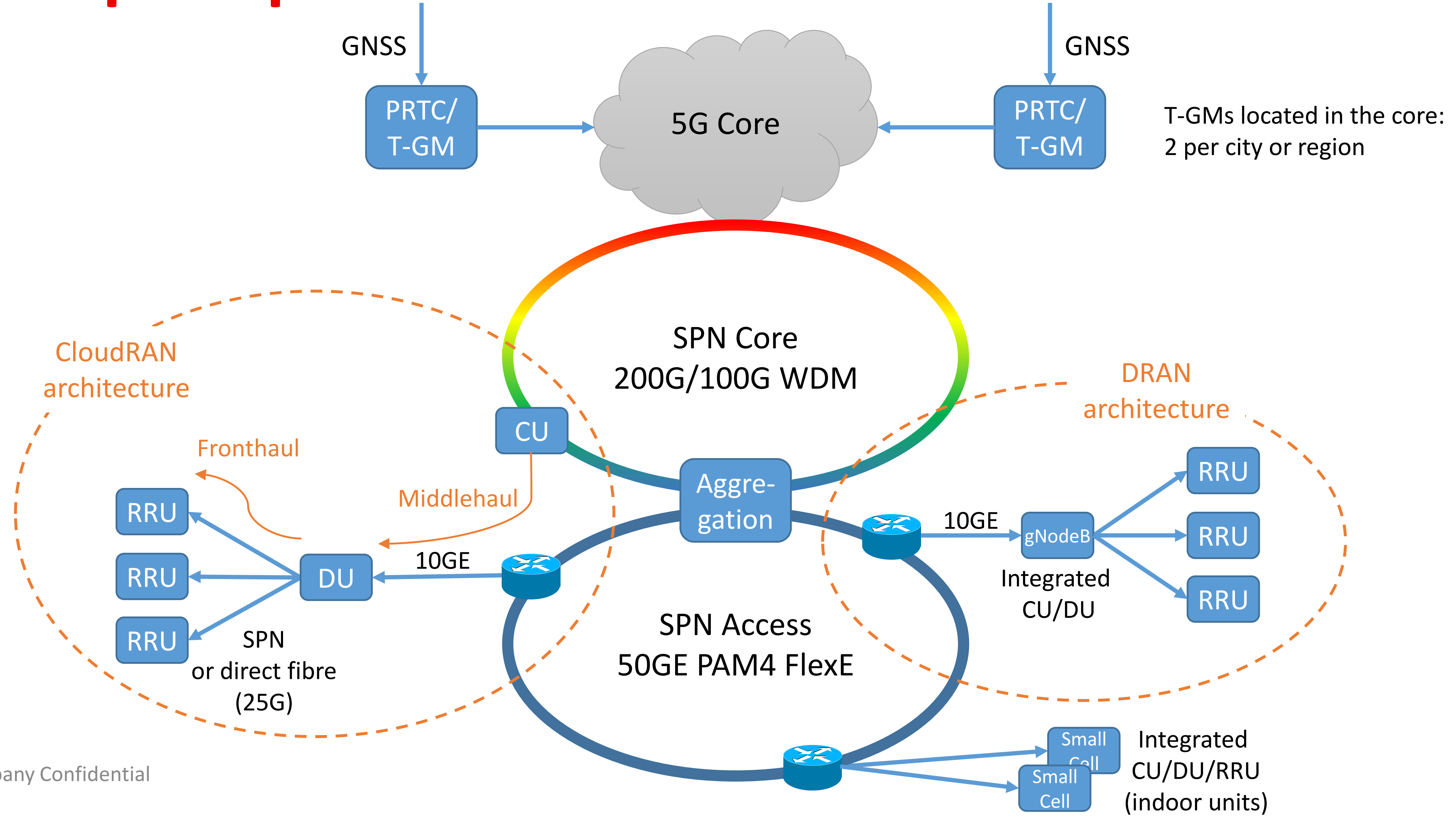
- Operators want a consistent, unified network for backhaul, middlehaul and fronthaul that support the slicing concept
    - China Mobile proposing the “Slicing Packet Network”, using FlexE technology for the transport network, and SDN for the control
    - China Telecom proposing a “Mobile OTN” approach, using FlexO technology for the transport network
- FlexE – originally developed by OIF for datacentres
    - Based on standard Ethernet physical layer
    - Provides a flexible way of matching interface speeds to link speeds
    - Facilitates network slicing
- FlexO – developed by ITU
    - Similar to FlexE, but for OTN
    - Uses DWDM to achieve shared network efficiency

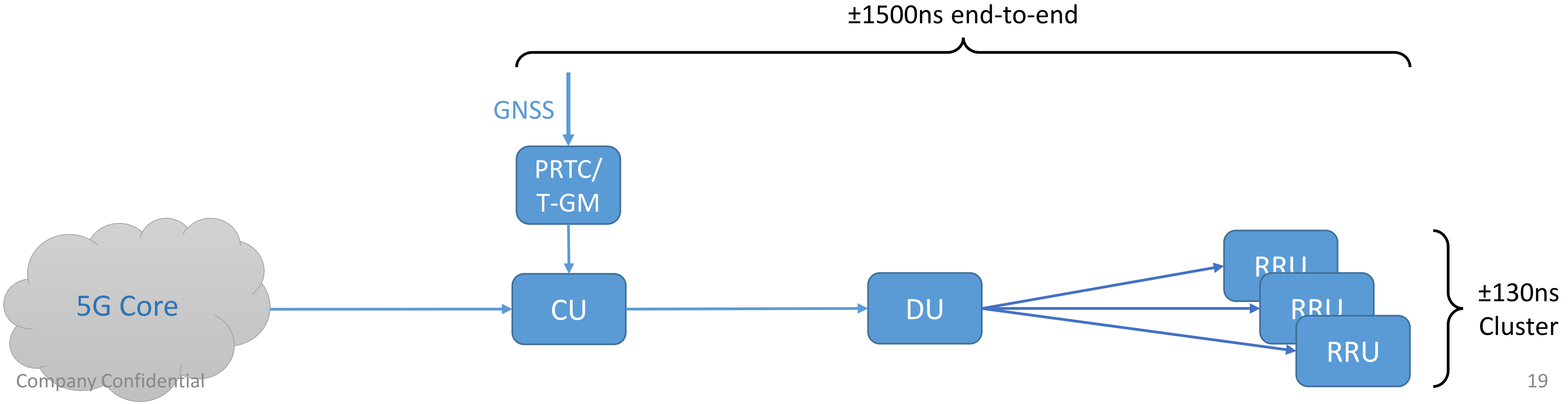
# Example Operator Network



# Enhanced Sync Specifications for 5G

# 5G Synchronisation Requirements

- Standard 5G TDD networks require ±1.5μs end-to-end *(same as 3G and 4G)*
- Co-operative radio techniques (e.g. inter-site CA, CoMP, MIMO) require much tighter synchronisation when deployed – consensus seems to be around ±130ns
  - BUT co-operative techniques take place in the DU
  - ±130ns is only required between RRUs connected to the same DU
  - This permits “sync clusters” of very tightly synchronised elements



# Synchronisation in LTE and 5G Networks

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| Radio Technology | Radio Interface Specification | | | Network Interface Specification | | |
|---|---|---|---|---|---|---|
| | Frequency | Phase[1] | 3GPP Spec. | Frequency | Time | ITU Spec. |
| LTE (FDD) | ±50 ppb (wide area)<br>±100 ppb (local area)<br>±250 ppb (home BS) | N/A | *Frequency:*[2]<br>36.104, sect. 6.5.1 | ±16 ppb | N/A | G.8261.1[3] |
| LTE (TDD) | ±50 ppb | 10 µs (> 3km cell)<br>3 µs (≤ 3km cell) | *Phase:*<br>36.133, sect. 7.4.2 | ±16 ppb | ±1.1µs | G.8271.1 |
| LTE-A MBSFN | ±50 ppb | 5 µs | *Phase:*<br>36.133, sect. 7.25.2 | ±16 ppb | ±1.1µs | G.8271.1 |
| LTE-A CA | ±50 ppb | 260 ns | *Phase:*<br>36.104, sect. 6.5.3.1 | Carriers always transmitted from same site;<br>no separate network synchronisation requirement | | |
| 5G NR (FDD) | ±50 ppb | N/A | *Frequency:*[2]<br>38.104, sect. 6.5.1 | ±16 ppb | N/A | G.8261.1 |
| 5G NR (TDD) | ±50 ppb | 3 µs | *Phase:*<br>38.133, sect. 7.4.2 | ±16 ppb | ±1.1 µs | G.8271.1 |
| Synchronous EN-DC<br>*(LTE-5G DC)* | ±50 ppb | 3 µs<br>*(radio i/f budget)*[4] | *Phase:*<br>38.133, sect. 7.6.2 | ±16 ppb | ±1.1 µs | G.8271.1 |
| 5G NR<br>inter-band CA | ±50 ppb | 3 µs | *Phase:*<br>38.104, sect. 9.6.3.2 | ±16 ppb | ±1.1 µs | G.8271.1 |
| 5G NR<br>intra-band CA | ±50 ppb | 260 ns | *Phase:*<br>38.104, sect. 9.6.3.2 | ±16 ppb | ± 100ns<br>*(under study)* | G.8271.1<br>*(under study)* |
| 5G NR MIMO | ±50 ppb | 65 ns | *Phase:*<br>38.104, sect. 9.6.3.2 | Co-located antennas assumed;<br>no separate network synchronisation requirement | | |

# Indoor Positioning

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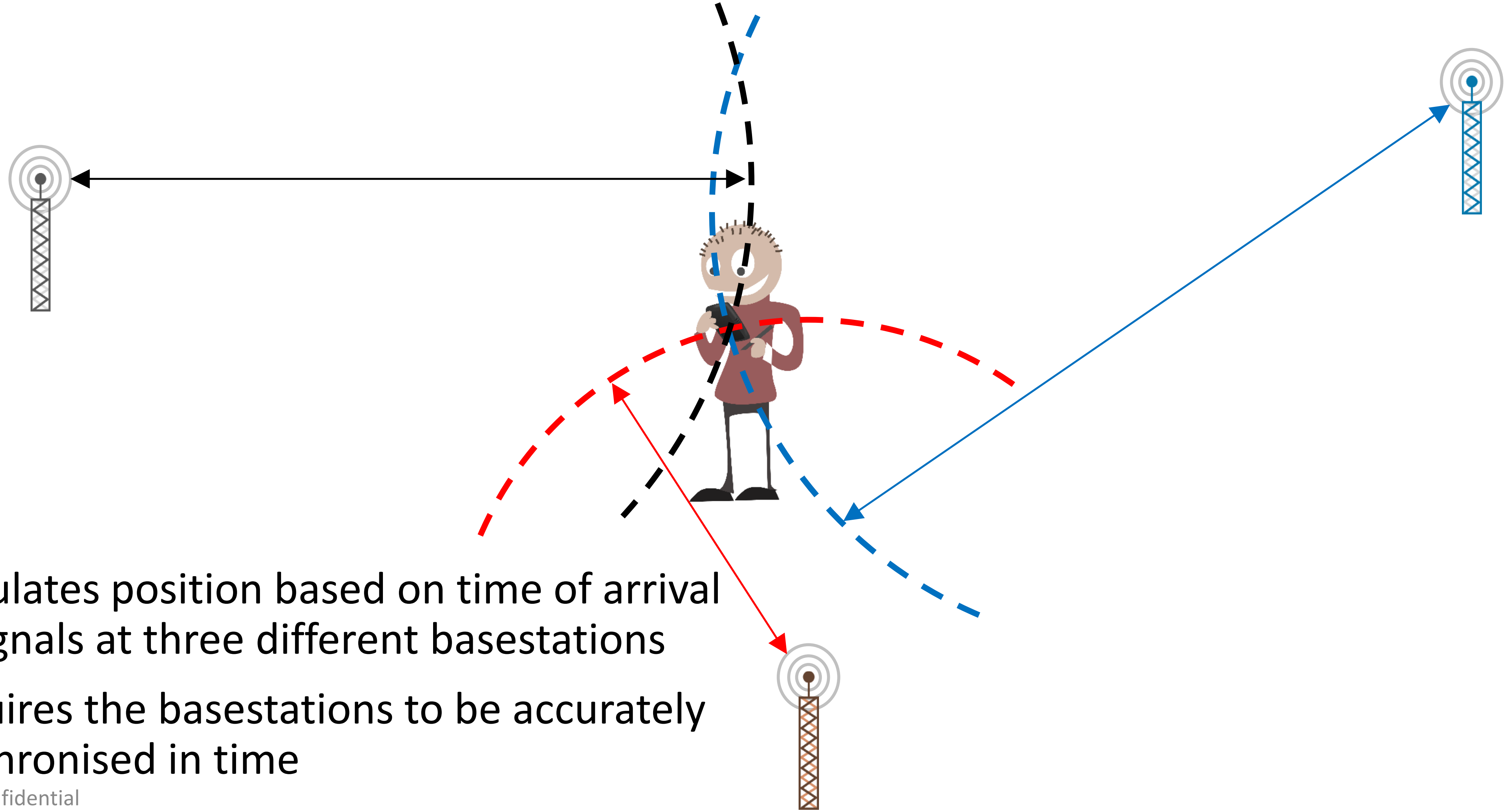
- For outdoor positioning there is GPS
  - Precision GPS vendors claim centimetre level accuracy
  - Applications include:
    - Precision Agriculture – GPS controlled ploughs, harvesters etc.
    - Stock control – container location in a shipyard
    - Autonomous vehicles
- But what about indoors?
  - Warehousing – where is my stock?
  - Autonomous vehicles in tunnels or underground parking lots
  - Sensor networks – where is the sensor?
  - Emergency location – in a large building, it may take a long time to find someone needing emergency assistance
- Competing technological solutions
  - WiFi, Bluetooth, 5G all looking at satisfying indoor positioning needs

# Observed Time Difference of Arrival



- Calculates position based on time of arrival of signals at three different basestations
- Requires the basestations to be accurately synchronised in time

# Positioning Requirements

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- E911: within 50m horizontal accuracy for 80% of emergency calls
  - Using OTDOA, requires time synchronisation to better than 150ns
- Targets for 5G “Higher Accuracy Positioning”: *
  - Accuracy level of <1m in 95% of the service area
  - Network-based positioning in 3D space to between 10m and <1m in 80% of situations
  - If implemented using OTDOA, requires time synchronisation to better than 3ns
- OTDOA not the only technique for positioning, but any positioning solution requires time to some degree



* 3GPP TR 22.862: Feasibility Study – Enablers for Critical Communications

# Network Protection and Reconfiguration

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- Networks are dynamic and sometimes fail
- Planned fail-over paths and protection must consider synchronisation
  - DU’s may be “multi-homed” – connected to more than one CU for protection purposes
  - Not always clear which RRUs are connected to which DUs
  - CloudRAN structure – RRUs may not share the same network section as the DU or CU, especially if dynamic reconfiguration occurs
- Therefore easier to plan for tight end-to-end synchronisation, rather than using “sync clusters”
- Example: China Mobile want a sync budget of ±200ns end-to-end

# Enhanced Clock Specifications for 5G

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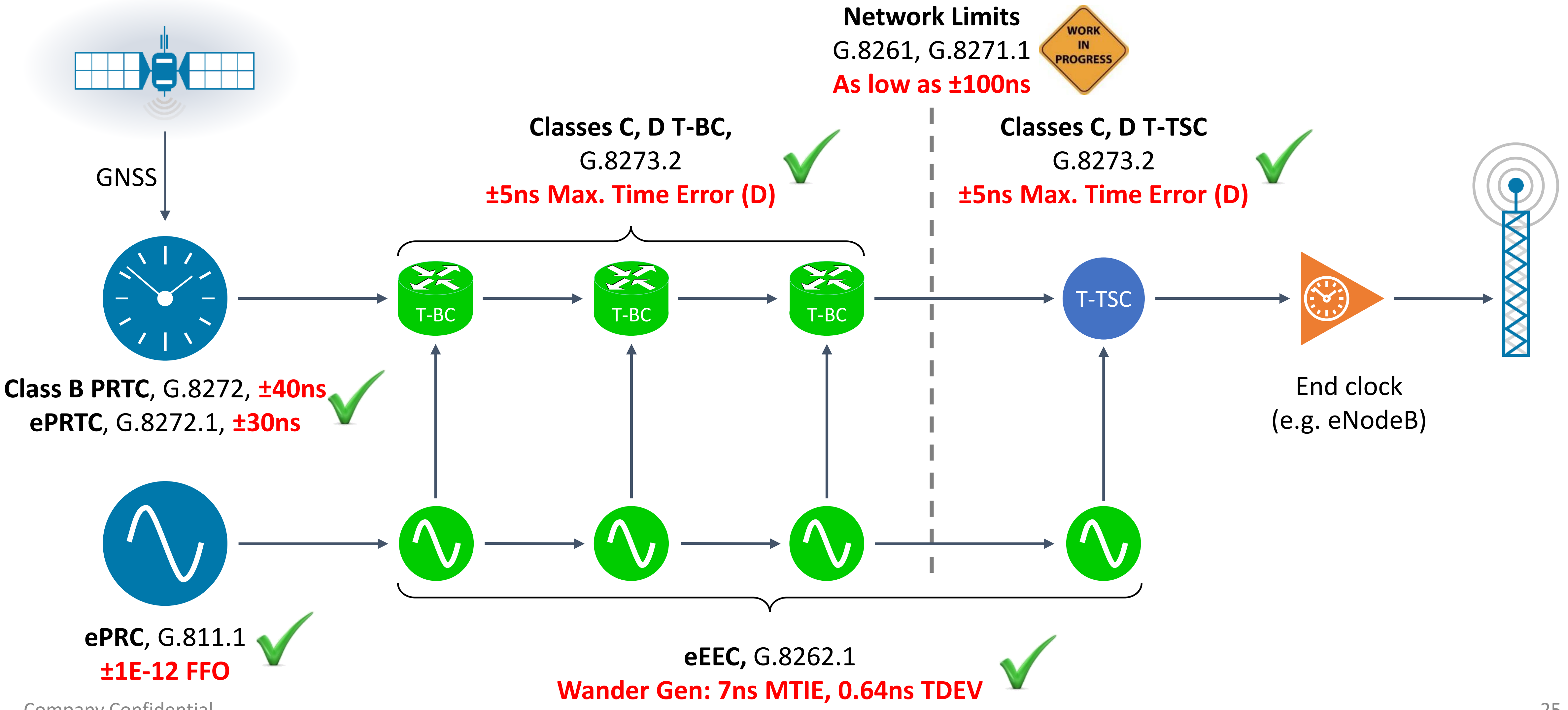

# Enhanced Specifications for 5G

Calnex

- G.8272: PRTC Class B
    - Time accuracy better than 40ns
    - Better solution than ePRTC (G.8272.1) for operators with distributed networks
    - Status: Agreed, to be published by December 2018
- G.8262.1: “eEEC”
    - Enhanced version compatible with current EEC, but improves noise generation, transients and holdover
    - Facilitates long-term assisted holdover of accurate time clocks, plus lower-noise T-BCs
    - Status: Agreed, to be published by December 2018
- G.8273.2: “Class C” and “Class D” T-BC and T-TSC to be developed
    - Exhibits lower noise generation and better SyncE-assisted holdover
    - Status: Agreed, to be published by December 2018
- G.8261: Network Limit for chain of eEECs
    - Network limit much lower, to permit better SyncE-assisted holdover of T-BCs and T-TSCs
    - Status: expected completion by mid 2019
- G.8271.1: Network Limit for chain of T-BCs
    - To be based on Class C, D T-BC specification, targeting around ±130ns end-to-end
    - Status: expected completion by mid 2019

# Comparing G.8262 to G.8262.1

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| Parameter | EEC (G.8262) | eEEC (G.8262.1) – agreed values |
|---|---|---|
| Frequency Accuracy | 4.6ppm | Same value |
| Pull-in/Hold-in | 4.6ppm | Same value |
| Wander generation | MTIE: 40ns @ 0.1s, rising to 113ns @1000s<br>TDEV: 3.2ns @ 0.1s, rising to 6.4ns @1000s | MTIE: 7ns @ 0.1s, rising to 25ns @1000s<br>TDEV: 0.64ns @ 0.1s, rising to 1.28 ns @1000s |
| Wander tolerance | 250ns @ 0.1s, rising to 5000ns @ 1000s | Same value *(allows mixed chains)* |
| Jitter generation | 0.5UI *(1G, 10G)*<br>1.2UI *(25G lanes)* | Same value (1G)<br>10G, 25G: for further study |
| Jitter tolerance | 250ns @ 10Hz, reducing to 1.5UI<br>(3.6UI for 25G lanes) | Same value (1G)<br>10G, 25G: for further study |
| Clock Bandwidth | 1 – 10Hz | 1 – 3Hz |
| Transient response | 120ns initial step, then 50ns/s *(const. temp)* | 10ns initial step, then 10 ns/s *(const. temp)* |
| Holdover | 120ns initial step, then 50ns/s frequency offset, plus 1.16 x $10^{-4}$ ns/$s^2$ drift *(const. temp)* | 10ns initial step, then 10 ns/s frequency offset, plus 1.16 x $10^{-4}$ ns/$s^2$ drift *(const. temp)* |

Key: Green – same as G.8262 EEC spec
Red – changes to G.8262 EEC spec

# G.8273.2: Comparing T-BC Classes

| Parameter | Conditions | Class A | Class B | Class C *(agreed)* | Class D *(agreed)* |
|---|---|---|---|---|---|
| Max\|TE\| | Unfiltered, 1000s | 100ns | 70ns | 30ns | *(15ns provisional)* |
| Max\|$TE_L$\| | 0.1Hz low-pass filter, 1000s measurement | - | - | - | 5ns |
| cTE | Averaged over 1000s | 50ns | 20ns | 10ns | *(4ns provisional)* |
| $dTE_L$ MTIE | 0.1Hz low-pass filter Const. temp, 1000s | 40ns | 40ns | 10ns | *(3ns provisional)* |
| | 0.1Hz low-pass filter Var. temp, 10000s | 40ns | 40ns | *FFS* | *FFS* |
| $dTE_L$ TDEV | 0.1Hz low-pass filter Const. temp, 1000s | 4ns | 4ns | 2ns | *(1ns provisional)* |
| $dTE_H$ | 0.1Hz high-pass filter Const. temp, 1000s | 70ns | 70ns | *FFS* | *(15ns provisional)* |

- Class C aimed at shorter chains (up to 10 nodes)
- Class D aimed at longer chains (up to 20 nodes), and fronthaul networks in particular
- All classes now defined over 1, 10, 25, 40 and 100GE interfaces

# G.8272: Comparing PRTC-A to PRTC-B

| Parameter | Conditions | Class A | Class B |
|---|---|---|---|
| Max\|$TE_L$\| | 1pps: unfiltered<br>PTP: 100-sample moving average low-pass filter | 100ns | 40ns |
| $dTE_L$ MTIE | 1pps: unfiltered<br>PTP: 100-sample moving average low-pass filter | 100ns (max) | 40ns (max) |
| $dTE_L$ TDEV | 1pps: unfiltered<br>PTP: 100-sample moving average low-pass filter | 3ns, rising to 30ns @ 1000s | 1ns, rising to 5ns @ 500s |

- PRTC-B intended for distributed applications where an ePRTC would not be practical
- Expected to be based on multi-band GNSS receivers to compensate for the ionosphere
- Holdover provided by SyncE rather than a Cs oscillator (as used in the ePRTC)

# Insight and Innovation

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