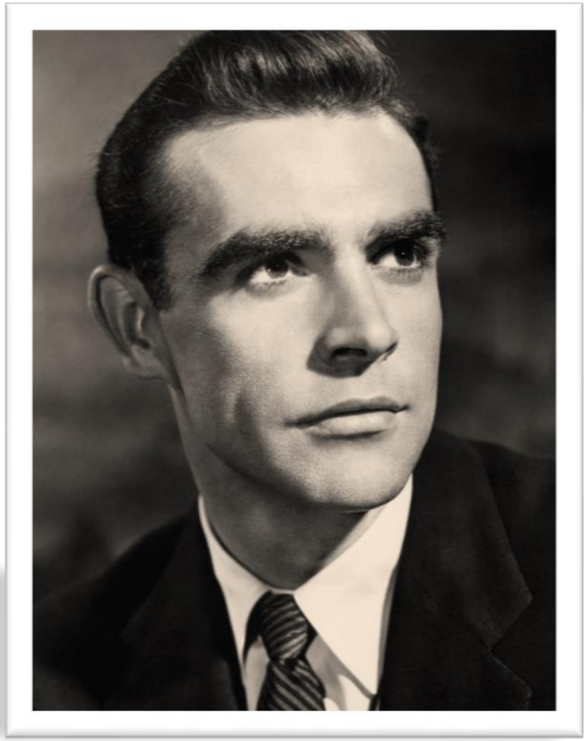
Why do mobile networks rely on GNSS?

Tim Frost | INC 2019, Edinburgh

Welcome to Edinburgh!

World Famous Local Residents



Alexander Graham Bell

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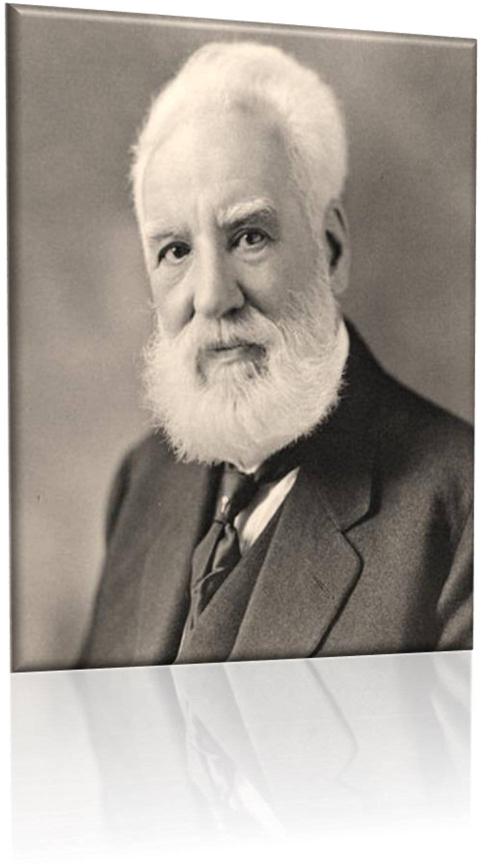

- Born Edinburgh, 1847
- Scottish scientist, inventor, engineer and innovator who is credited with inventing the first **practical telephone.**
- 1888: one of the founding members of the National Geographic Society.
- Many other invention, include groundbreaking work in optical telecommunications, hydrofoils and aeronautics.

James Clerk Maxwell

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- James Clerk Maxwell born at 14 India Street, Edinburgh, 1831.
- 1847: Edinburgh University
- 1850: Cambridge University (First Class Honours Mathematics)
- 1860: Became Professor of Physics and Astronomy at King's College in London. This time is especially known for the advances Maxwell made in the fields of electricity and magnetism.
- 1871: First Cavendish Professor of Physics

Dolly the Sheep

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- Born Edinburgh,1996.
- Cloned by Ian Wilmut, Keith Campbell and colleagues at the Roslin Institute near Edinburgh in Scotland.
- Dolly was born to three mothers (one provided the egg, another the DNA and a third carried the cloned embryo to term).
- On Dolly's name, Wilmut stated "Dolly is derived from a mammary gland cell and we couldn't think of a more impressive pair of glands than Dolly Parton's".

A brief history of timing

A brief history of timing (in telecoms)

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- “Mr. Watson, come here, I want to see you.”
  - First telephone call by Alexander Graham Bell, 10 March 1876
- Phones connected directly by copper wire – and stayed that way for over 60 years
  - First FDM systems “L-carrier” introduced in the 1940s
  - First digital TDM systems “T-carrier” introduced in the 1960s, multiplexing 64kbit/s voice channels

After about 100 years…

- Digital switches introduced in early 1970s
  - Voice calls were no longer converted back to analogue for switching, but could be switched directly from one TDM circuit to another
- Digital switches required the phone calls being switched to have the same 8kHz sample rate
  - "Slips" (missing or extra samples) were introduced if the sample rates were different
  - Required the whole infrastructure to be based on the same master clock
  - Switches were frequency synchronised by using dedicated links, driven from a central Primary Reference Clock (PRC)
- Synchronisation in telecoms was born!
  - Only frequency synchronisation (or ***syntonisation***) is required

Synchronisation in mobile systems

Frequency synchronisation in mobile systems

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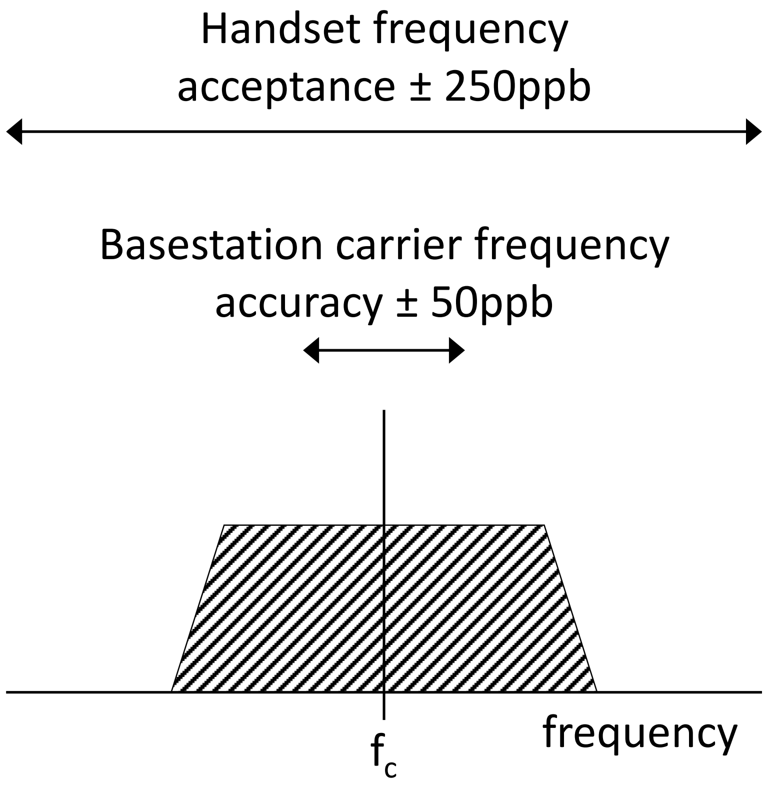
- Requirement: RF carrier frequency must be within 50ppb of the nominal value
- Reasons:
  - Regulation and licensing of spectrum
  - Interference with other basestations
  - Handoff for mobiles moving between cells
  - Quality of service
  - Doppler effect



Doppler Shift

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$$\Delta f = \frac{f_o . \Delta v}{c}$$

At 320km/h (200mph), Δf = 300ppb

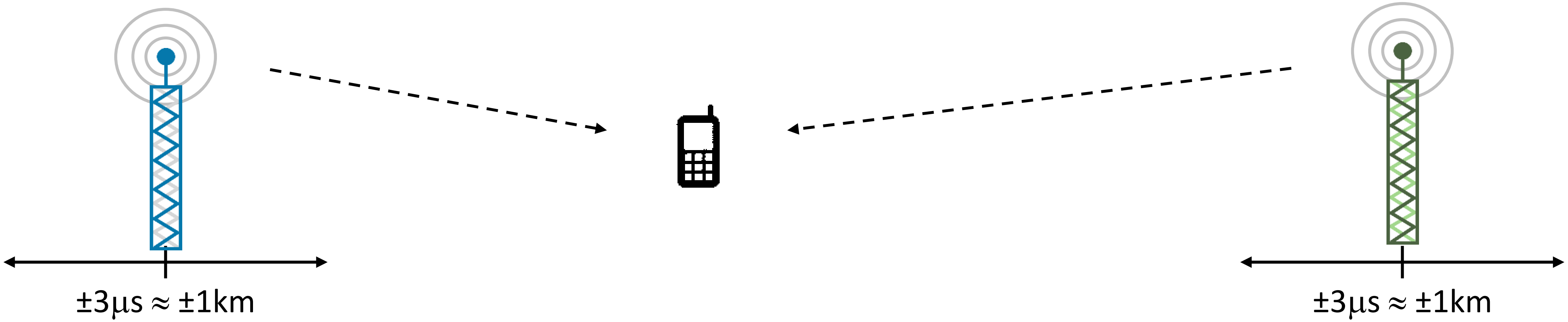
(mobile service might not work)

At 160km/h (100mph), Δf = 150ppb

(mobile service should work)

Time Synchronisation

- GSM, UMTS (European 2G and 3G mobile standards):
  - no requirement for time synchronisation, only frequency
- cdmaOne, cdma2000 (N. American 2G and 3G mobile standards):
  - Basestations must be within 3μs of system time (10μs holdover)
  - GPS used at every basestation to provide a system time reference
- Required for "soft handoff"
  - "Pilot signal" from both basestations must arrive within a few microseconds of each other to handoff
  - First signal to arrive is assumed to be the nearest

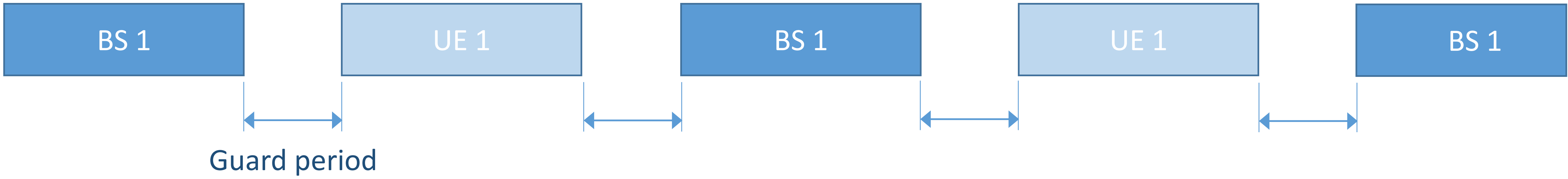


LTE (4G Mobile)

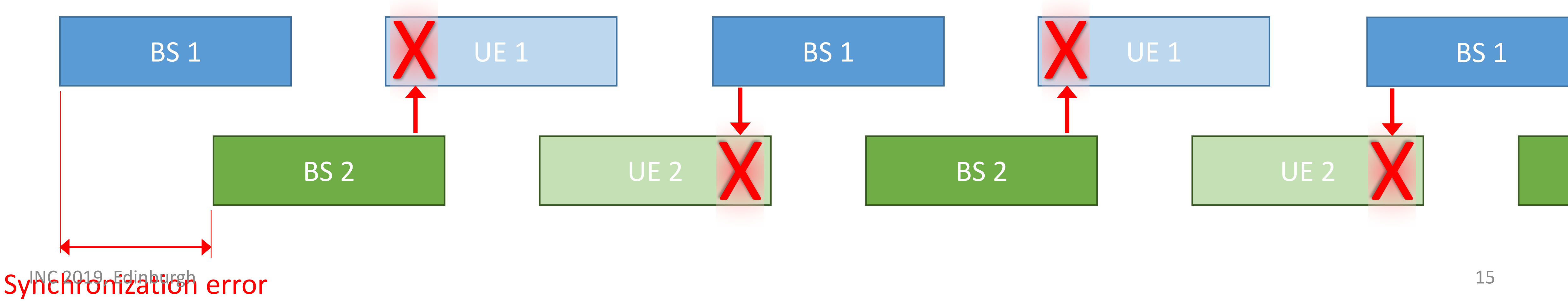
- ***LTE FDD*** *(upstream and downstream on different frequencies)*
  - Same 50ppb requirement for frequency synchronisation
  - No requirement for time synchronisation
- ***LTE TDD*** *(upstream and downstream in different time slots)*
  - Same 50ppb requirement for frequency synchronisation
  - Requires phase alignment between neighbouring basestations
- Not much deployment of LTE TDD
  - Main exception: China

Why does TDD need synchronization?

- TDD networks alternate between upstream and downstream transmissions:

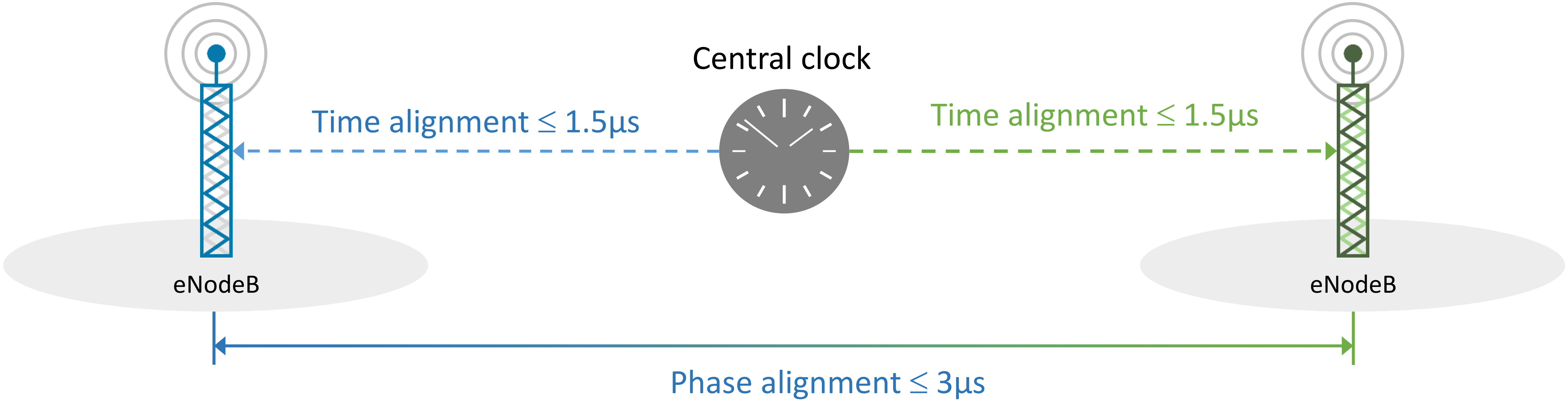


- If synchronization is poor between cells, a neighbouring cell transmission can interfere with UE transmissions:



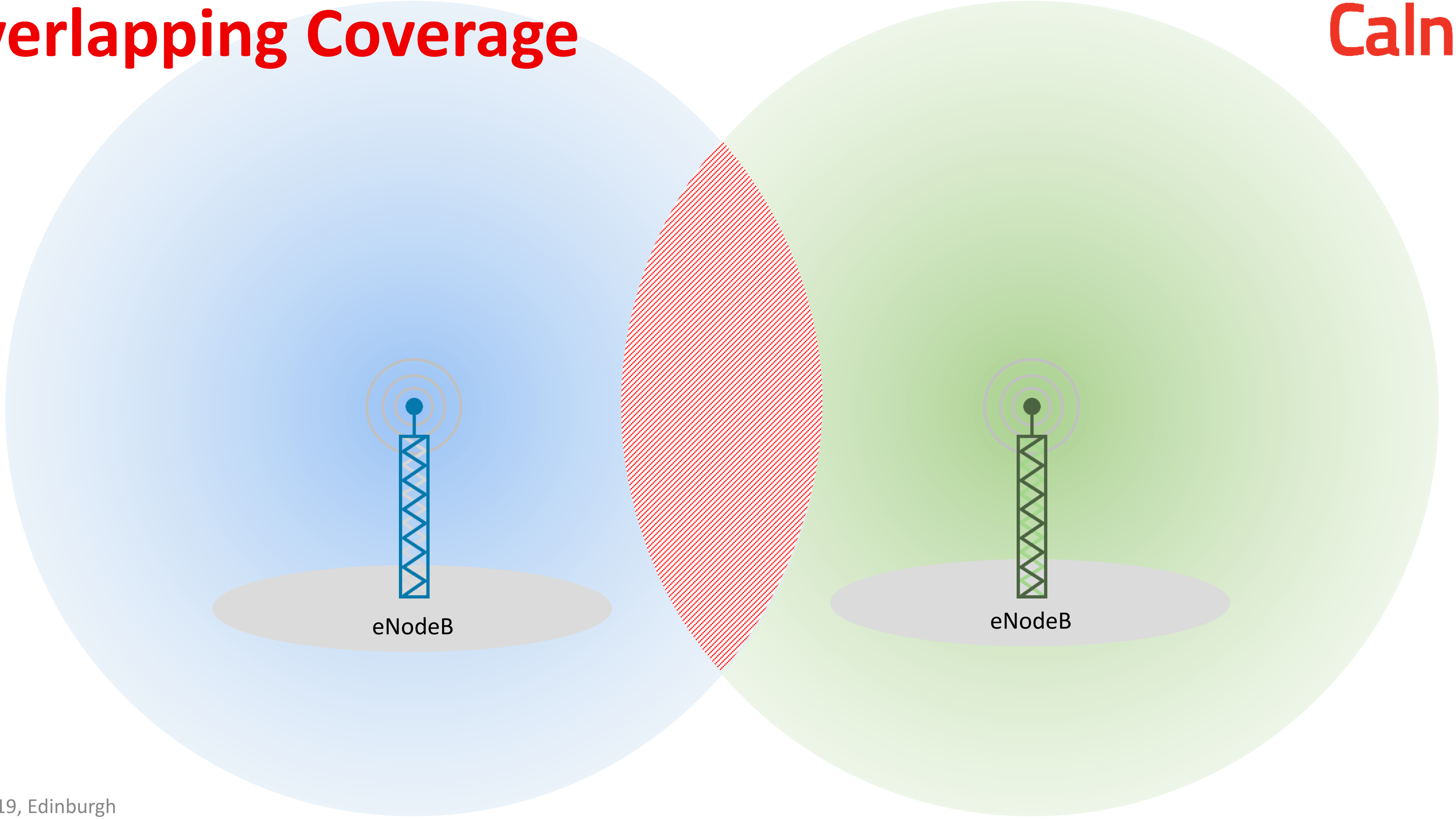
Synchronization Requirement

- ***Cell Phase Synchronisation Accuracy*** (CPSA):
  - "The maximum absolute deviation in frame start timing between any pair of cells on the same frequency that have overlapping coverage areas shall be ≤ 3µs" *
- This is a ***phase requirement*** (i.e. it is relative to the other cell), not a ***time requirement***
- It is normally implemented as a ***time requirement*** to a ***central clock***



* 3GPP TS 36.133, section 7.4

Overlapping Coverage



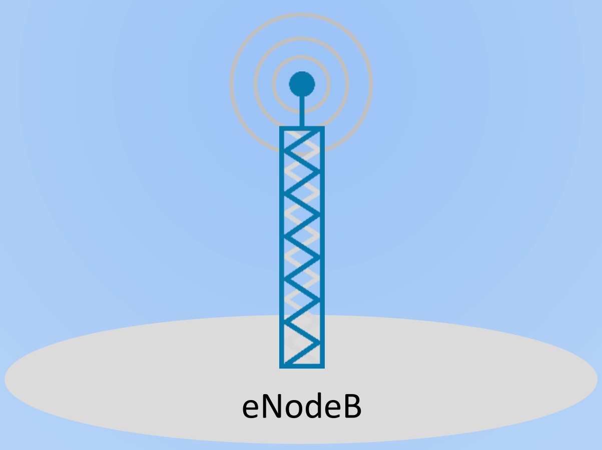
Interference Area

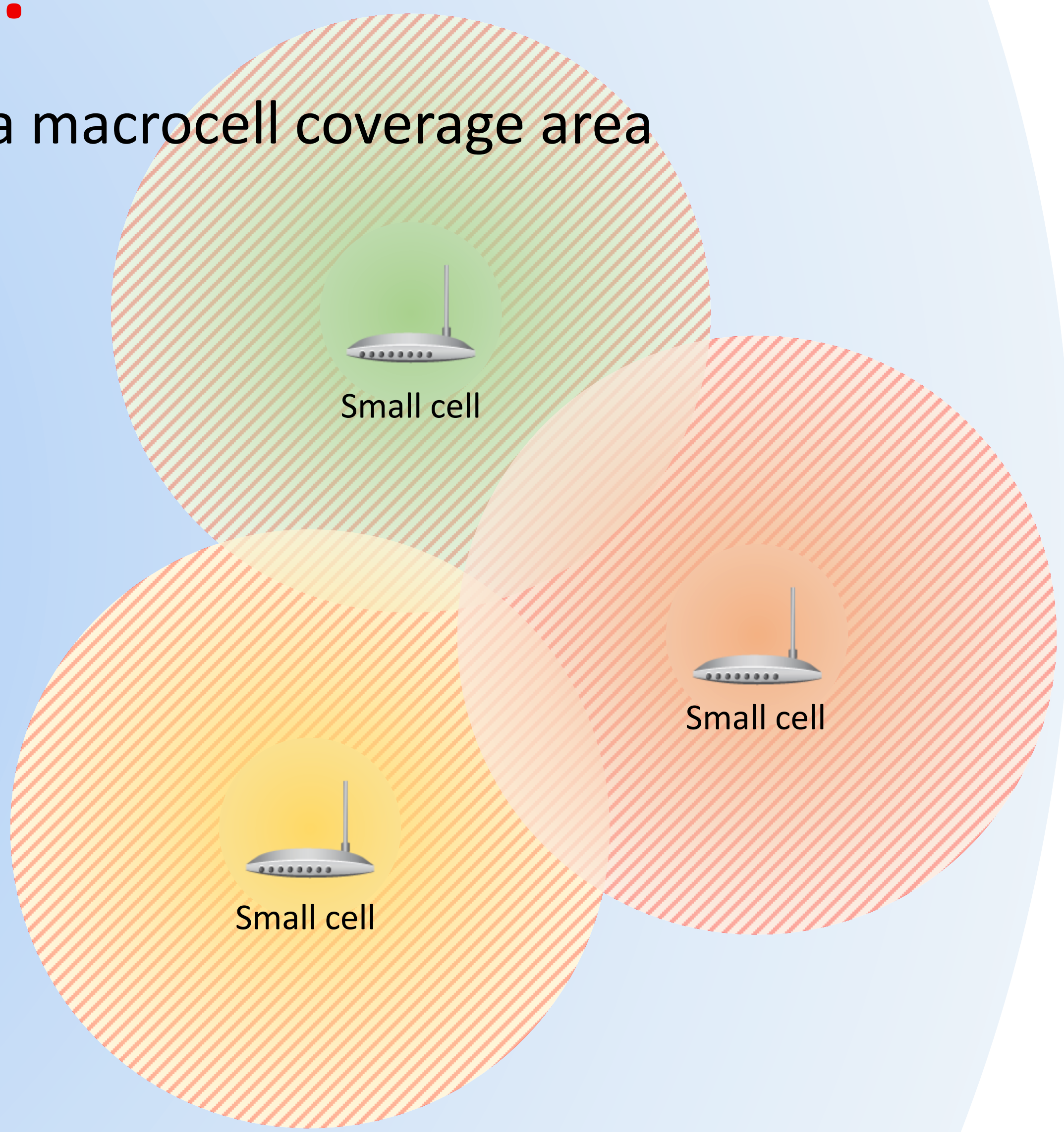
Interference due to

poor synchronization

What about small cells?

- Small cells are often entirely within a macrocell coverage area
- Synchronization errors may cause a significant interference problem

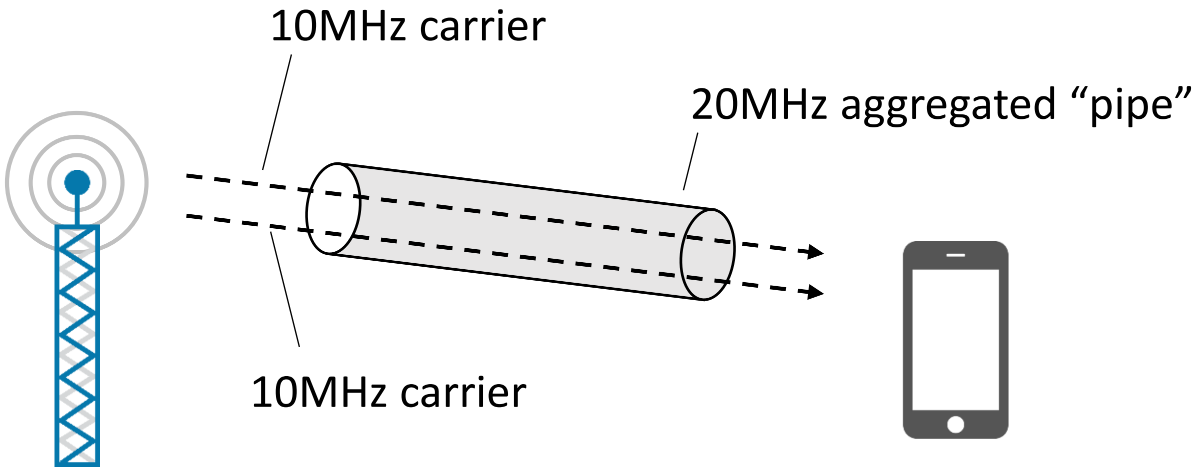




LTE Advanced

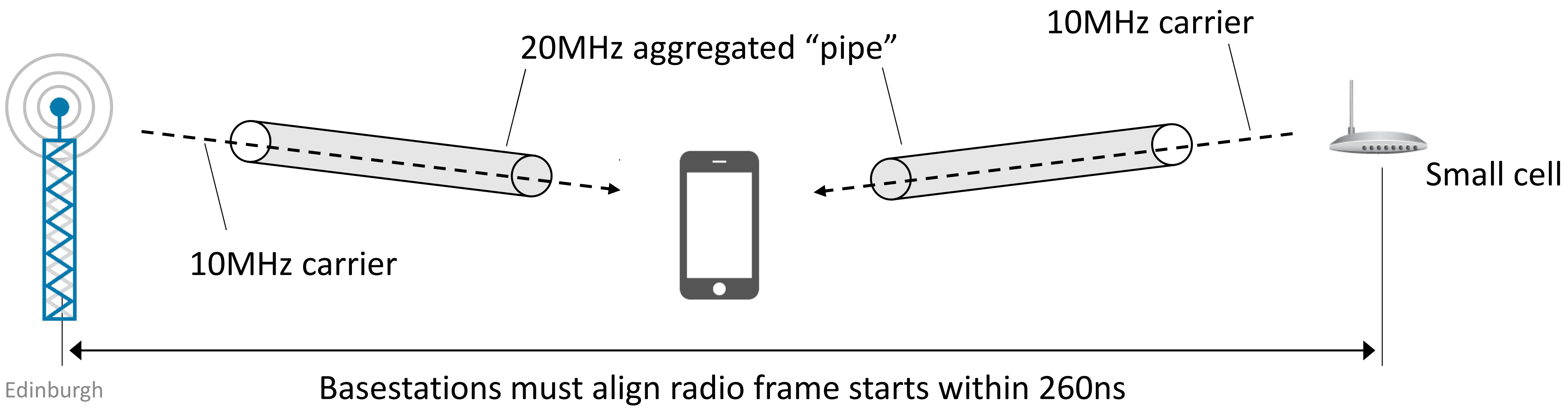
LTE Advanced (4.5G): Carrier Aggregation

- Carrier Aggregation bonds together two small carriers to make one big carrier
  - Radio frames must be aligned to within 260ns – called ***Time Alignment Error***, TAE
  - Normally transmitted from same antenna, so not a network synchronisation problem



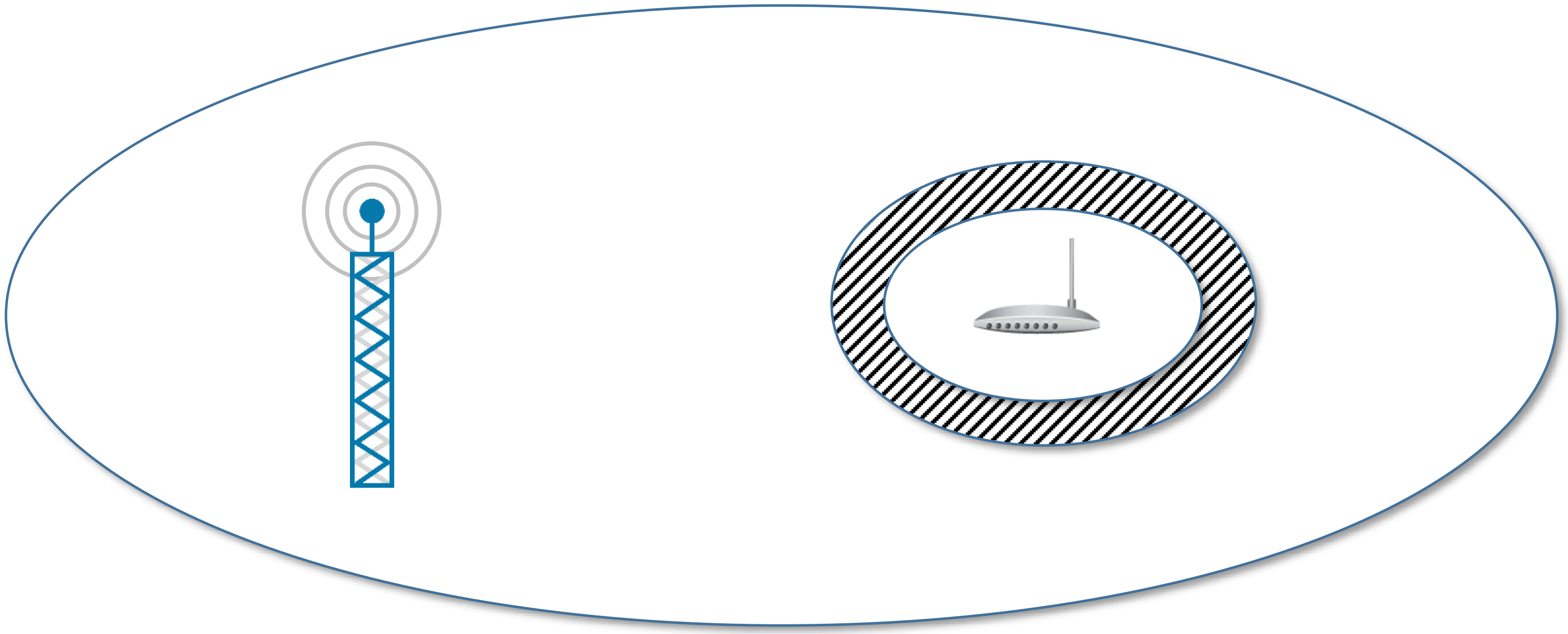
Inter-site Carrier Aggregation

- Carrier Aggregation bonds together two small carriers to make one big carrier
  - Radio frames must be aligned to within 260ns *(intra-band, contiguous CA)*
  - Normally transmitted from same antenna, so not a network synchronisation problem
- Inter-site carrier aggregation
  - Transmit second carrier from another basestation or small cell
  - Now there is a network synchronisation requirement of 260ns



LTE Advanced (4.5G): Small Cells

- LTE started dense deployment of “small cells” to meet demand in busy areas
- Small cells can cause interference, particularly around the cell edge
  - Solution: “Almost Blank Sub Frames” – macrocell reduces power temporarily so handsets can “hear” the small cell
  - Time synchronisation of ±1 to 5μs required to co-ordinate ABSF



Positioning

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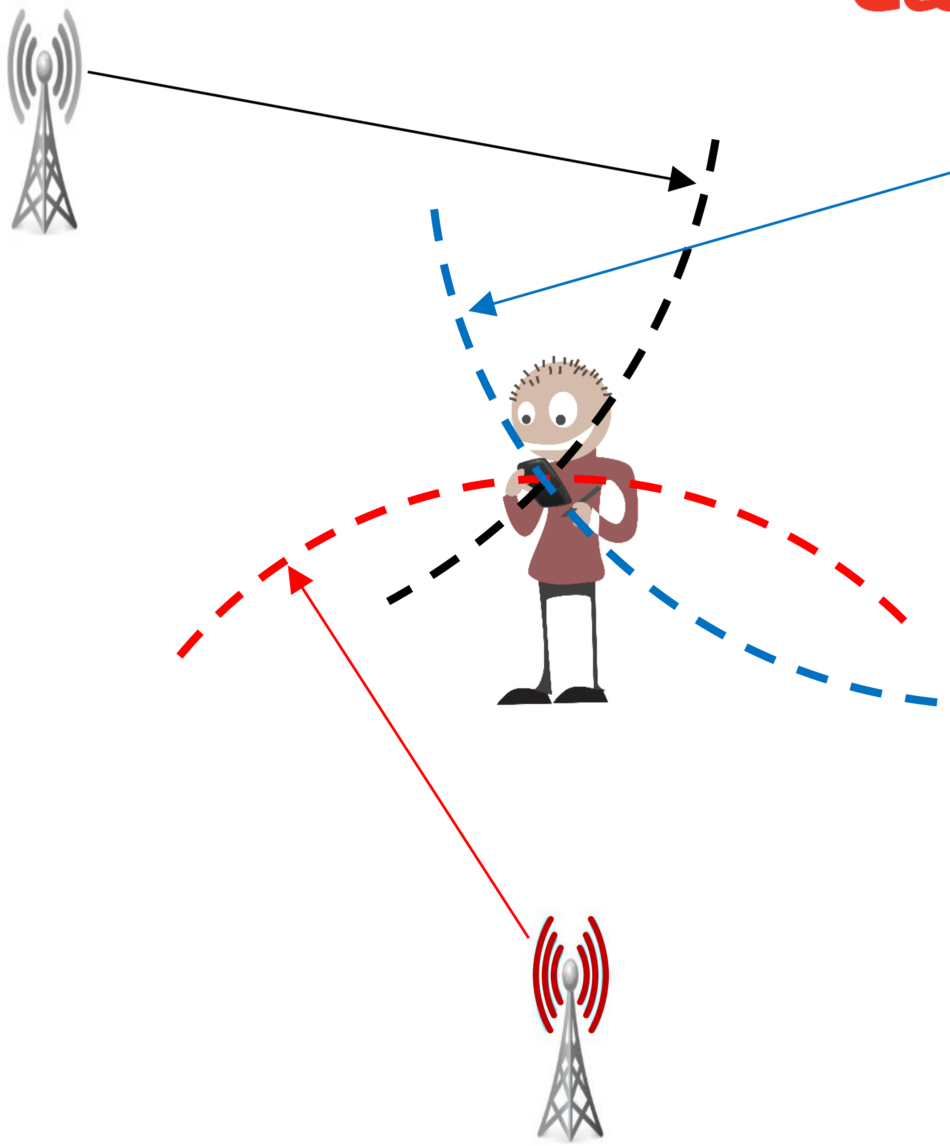
- Emergency calls require position of caller to be determined to within 50m
- Normally uses the GNSS receiver in your phone to determine position
  - Position not always available indoors
- Observed Time Difference of Arrival (OTDOA)
  - Calculates position based on time of arrival of signals from three different basestations
  - Requires the basestations to be accurately synchronised in time to within approx. 100ns
  - For indoor location, basestations might be close together, e.g. small cells or radio units



What’s coming with 5G?

What is 5G: the hype?

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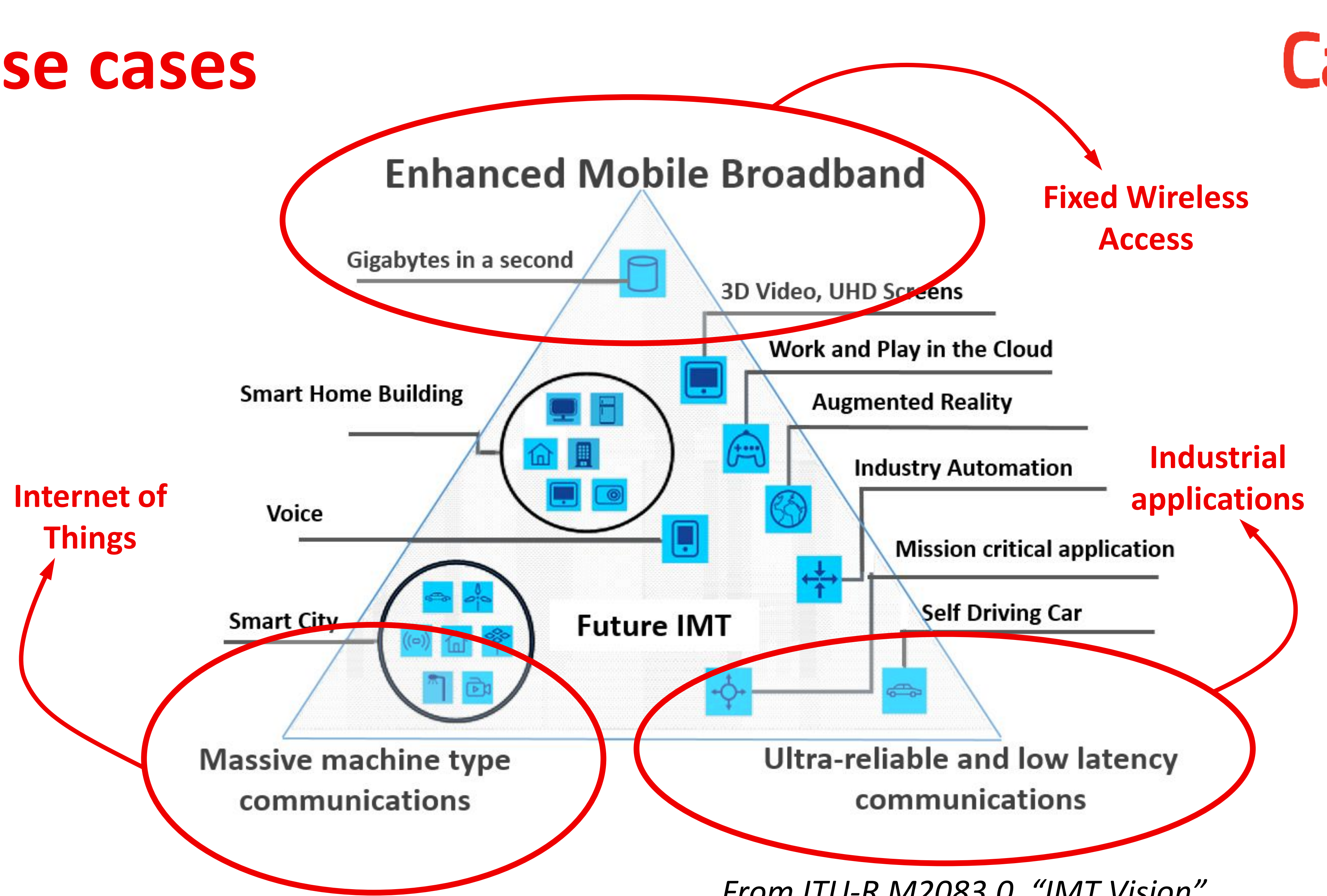
- *“5G is a wireless infrastructure to connect the world” **
- It’s going to solve everything from glitchless 8K video streaming to world poverty…
- Goals for 5G*:
  - Promote a new ICT market to help drive economies around the globe
  - Bridge the digital divide by providing affordable, sustainable mobile and wireless communications
  - Enable new ways of communication, sharing content anytime, anywhere through any device
  - Enable new forms of education, boosting e-learning, e-health and e-commerce
  - Promote energy efficiency by supporting smart gird, smart logistics and teleconferencing
  - Social changes through shared opinions and information
  - New art and culture; virtual group performances, art and activities

** From ITU-R M2083.0, “IMT Vision”*

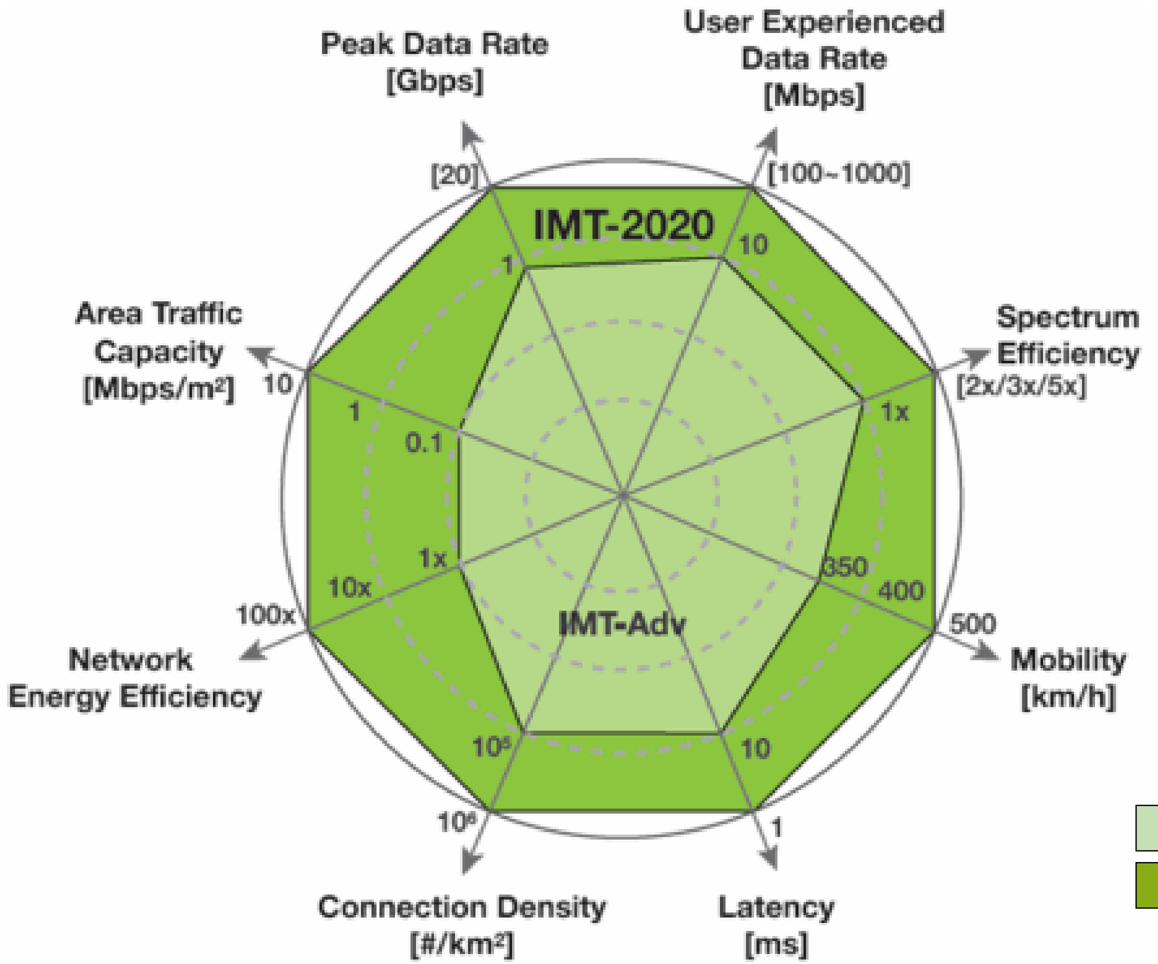
Main use cases



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

Performance objectives

- **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?

- 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 synchronisation requirements

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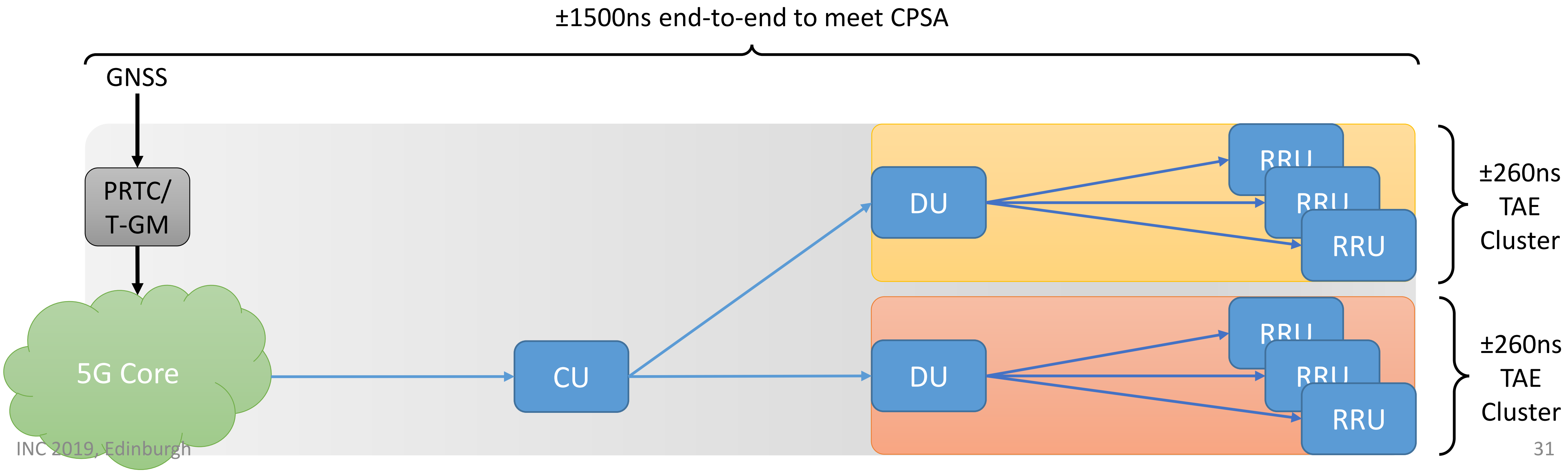
- In previous mobile generations (e.g. 3G WCDMA, 4G LTE) most operators deployed FDD
  - No time synchronisation requirements
- Some TDD deployments *(notably China, some other countries)*
  - **Cell Phase Synchronisation Accuracy (CPSA) requirement of 3µs** met by using a common time reference
- For 5G NR, most deployments will be TDD
  - **CPSA** is still **3µs** for 5G NR
  - **TAE** requirements also valid for Carrier Aggregation
    - **Inter-band CA** – TAE requirement is **3µs**
    - **Intra-band CA (non-contiguous)** – TAE requirement is **3µs**
    - **Intra-band CA (contiguous)** – TAE requirement is **260ns** or **130ns** (depending on frequency band)
- It is much harder to meet 260ns using a centrally-located common reference clock

Frontthaul Clusters

- Basestations for NR are exploded into three parts
  - Central Unit (CU), Distributed Unit (DU) and Remote Radio Unit (RRU)
- Carrier Aggregation and OTDOA protocols run in the DU
  - This permits "sync clusters" of very tightly synchronised elements



What’s this got to do with GNSS?

Time is relative

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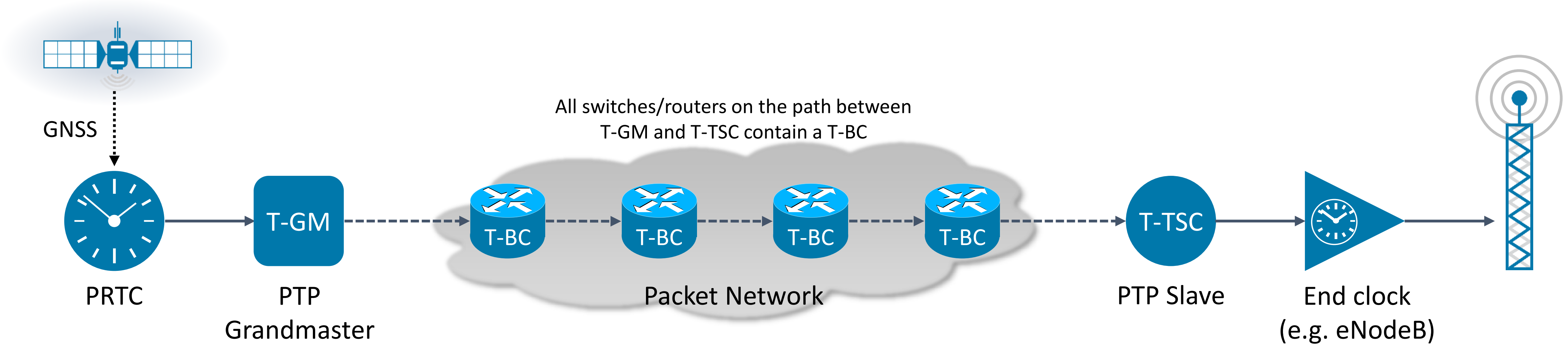
- There is no such thing as “absolute time”
- All we can do is count regular events
  - Astronomical events (days, months, years)
  - Physical events (pendulum swings, quartz vibrations, Caesium atom resonances)
- “Common time” requires everyone to start counting at the same point, or “epoch”, and count at the same rate
- Example: a calendar counts days, months and years from a known starting point
  - Different calendars have different epochs
  - Epoch for the Gregorian calendar is the birth of Christ
  - Epoch for the Islamic calendar is the Hijra
- All “common time” is relative to the chosen epoch and counting rate

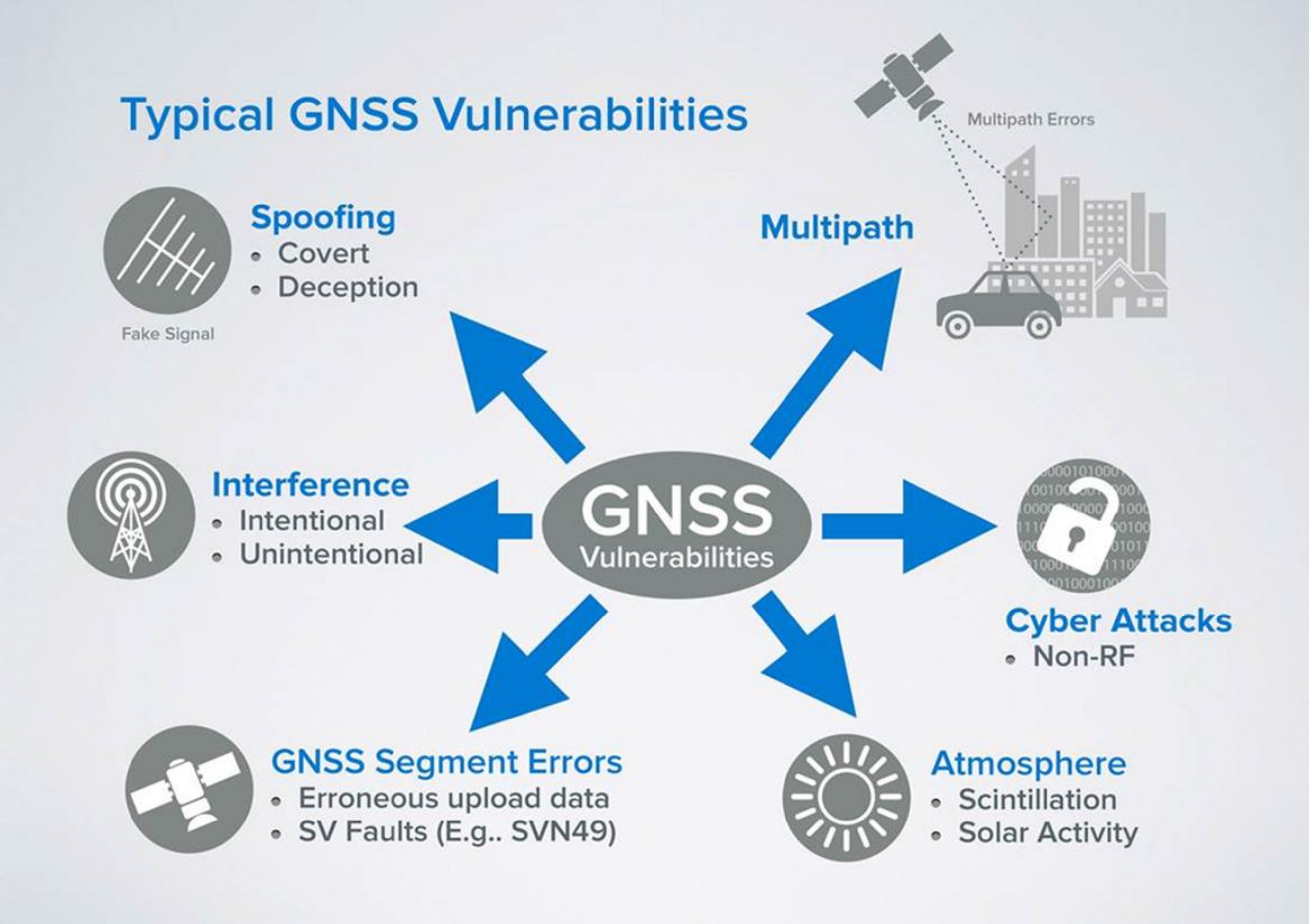
GNSS as a time reference

- GNSS is the main source of time into the telecoms network
  - Convenient means of distributing a common time reference over a wide area
- Timing then distributed using PTP (Precision Time Protocol) through the network
- ITU-T timing architecture example:



GNSS Vulnerabilities

- All the GNSS vulnerabilities that are applicable to navigation systems also apply to timing



Industry threats and vulnerabilities

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- Critical industries dependent on GNSS Timing
  - Telecoms
  - Power
  - Financial
  - Transport
- In the US, the Department of Homeland Security have a initiated a project looking at the vulnerability of critical industry to GNSS failures
  - Involving representatives from telecoms operators, vendors and the test and measurement community
- In Europe, the GSA have initiated several projects looking at resilient GNSS timing receivers
  - Two of them, “GEARS” and “GIANO” were presented a couple of weeks ago at the ITSF conference

Conclusions

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- Accurate time is fundamental to the coming 5G mobile network
- If mobile networks are essential services now, 5G has ambitions to be even more critical
- It’s not just mobile networks
  - Power generation and distribution
  - Financial trading
  - Automotive networks, both in-car and external
  - Manufacturing
- All these industries were represented at the recent ITSF conference (International Time and Synchronisation Forum)
- All are dependent on GNSS for time distribution, and subject to the same vulnerabilities as any other GNSS-based system

Insight and Innovation

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