Synchronisation Architectures for Small Cells

June, 2013

Symmetricom®

Small Cell Synchronisation Requirements

Mobile Synchronization Requirements
Macro & Small Cells

Mobile Standard	Frequency Accuracy: Transport / Air Interface	Phase
UMTS, LTE FDD Femto Cell	n/a / 100-200 ppb	
GSM / UMTS / W-CDMA		N/A
CDMA2000		±2.5 - 10 µs
TD-SCDMA	16 ppb / 50 ppb	± 1.5 µs
LTE -FDD		
LTE-TDD		± 1.5µs - ± 5µs
LTE eICIC		± 1.5µs / ± 5µs
LTE CoMP / MIMO		± 1.5 µs
LTE MBSFN		± 1 - 32 µs

Small Cell Deployments

Deployment Environments

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Railway stations

Stadiums

Shopping centres

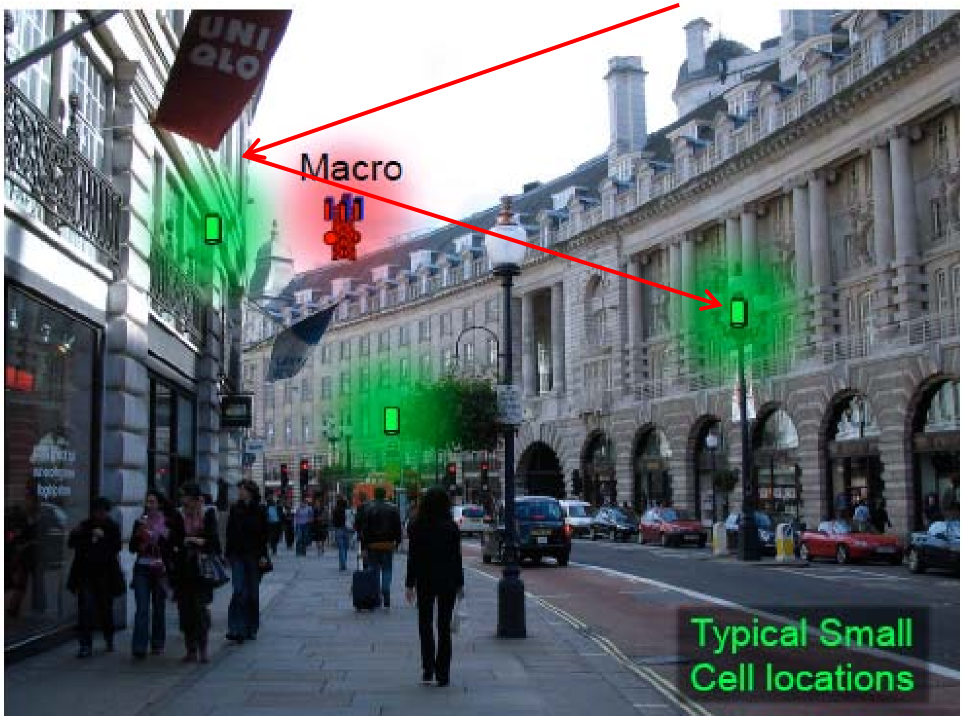
Airports

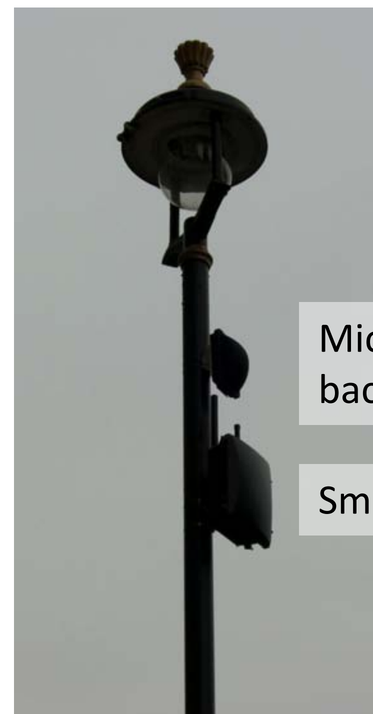
Gated communities and rural environments for coverage

Dense environments – these require interference control

Street deployment

- Urban canyons
  - Poor GNSS environment, multipath reflections and restricted sky view
- Difficult backhaul (est. 70% will be over uwave)
  - Typically NLOS or LOS microwave, not ideal for packet timing





Pictures from Telefonica wi-fi small cell trial, London, summer 2012

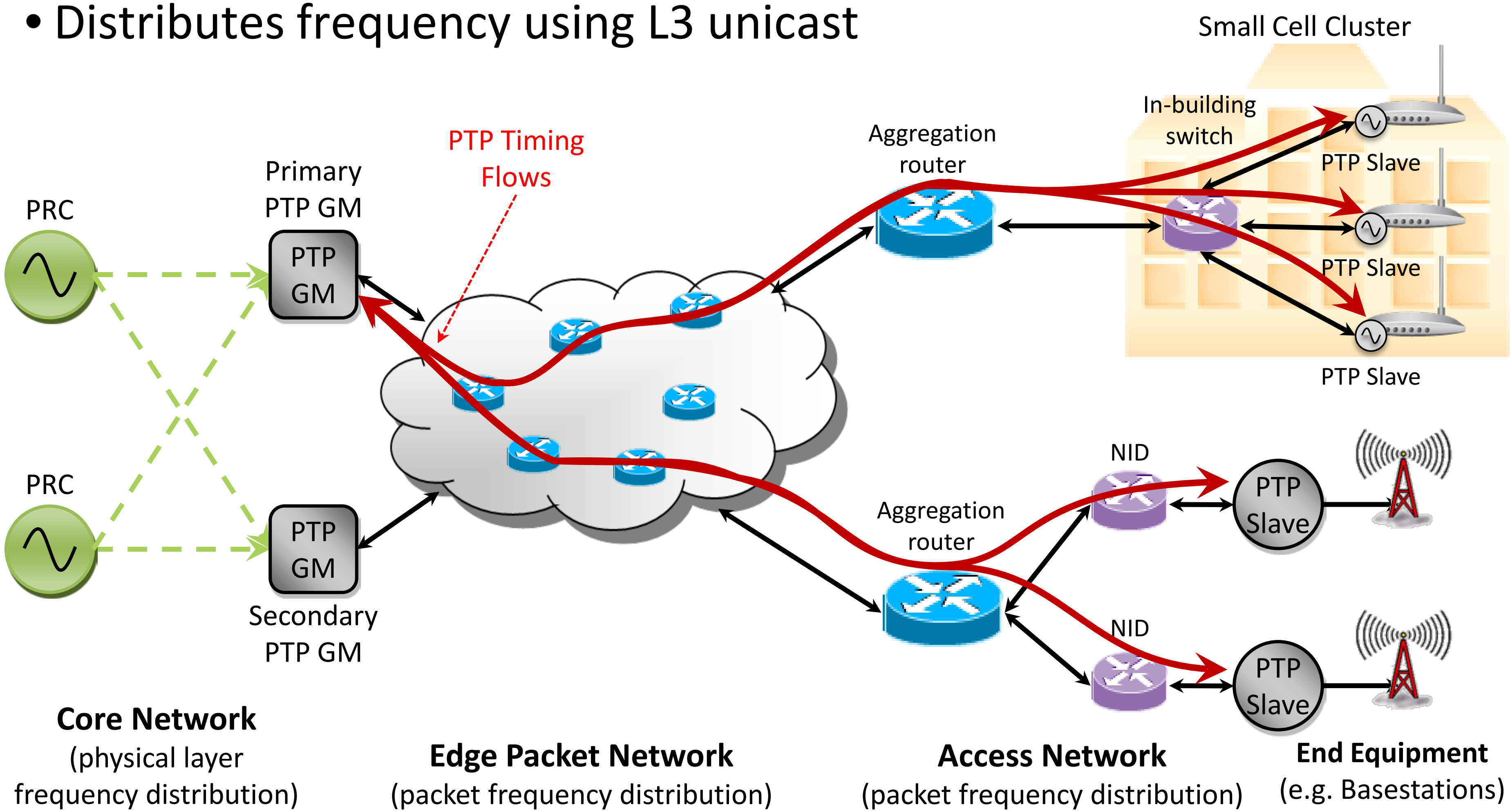
Small Cell Deployment Classes

- **Targeted capacity**
  - Extra capacity for busy “hotspot” areas
  - Examples: street deployment, railway stations
- **Non-targeted capacity**
  - Additional capacity for areas to improve quality of experience
  - Example: “dense urban underlay”, street deployment
- **Indoor coverage**
  - Coverage for indoor locations where macrocell signal is patchy
  - Examples: shopping centres, airports, stadiums, residential
- **Outdoor coverage**
  - Coverage for outdoor locations where macrocells are not viable
  - Examples: rural “notspots”, exclusive developments

PTP Network Architecture Options

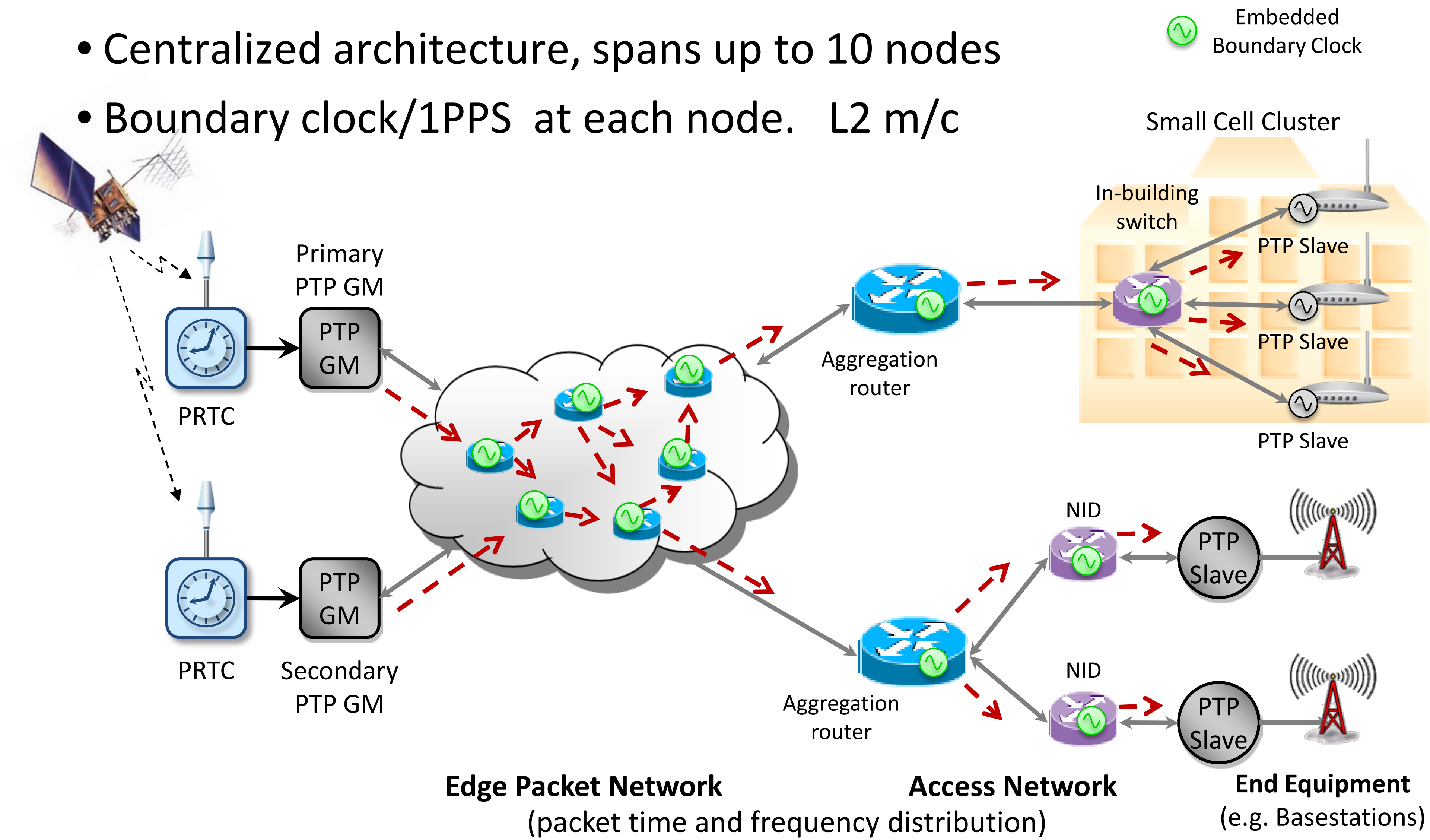
PTP Network Frequency Distribution: G.8265.1

- Centralized architecture, spans up to 10 nodes
- Distributes frequency using L3 unicast



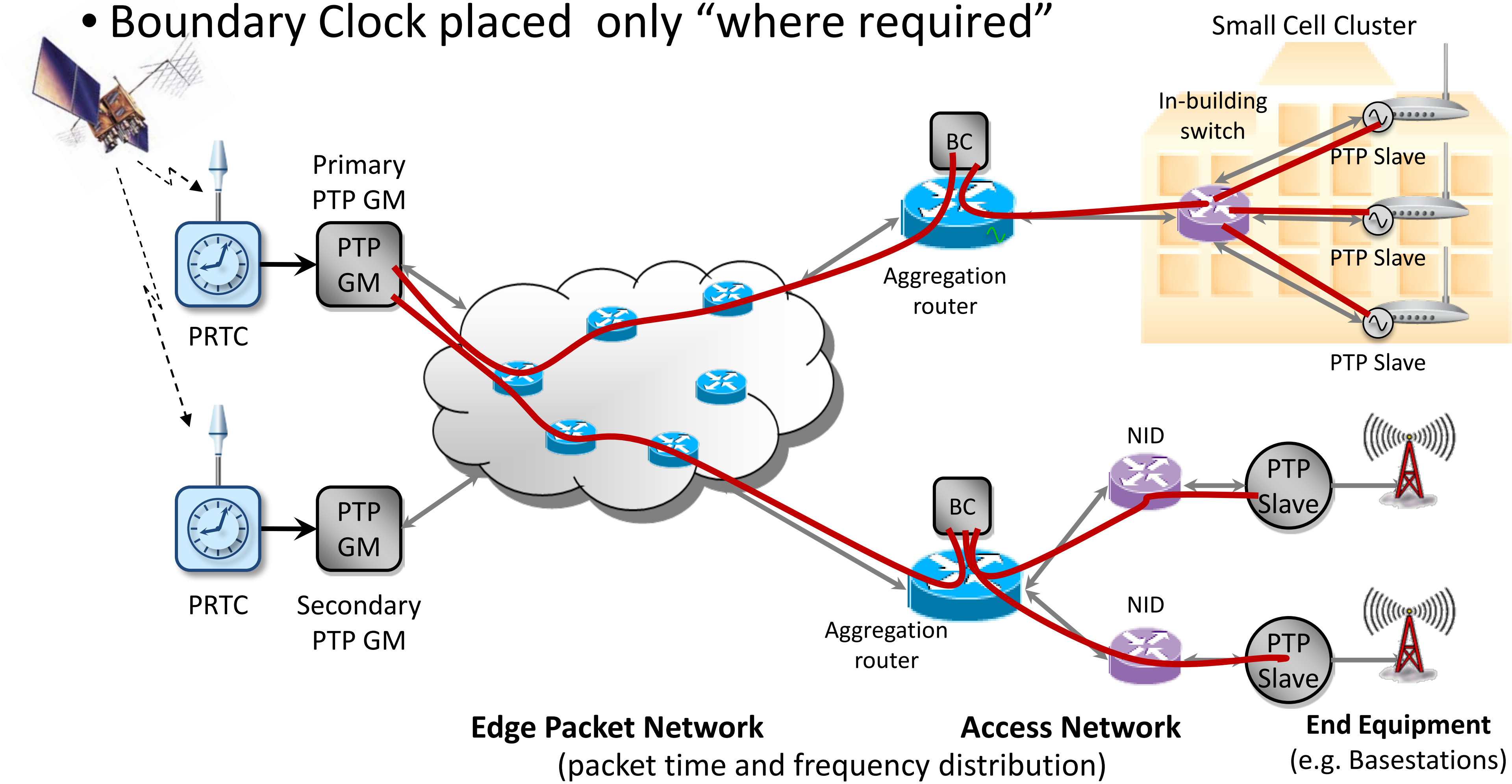
PTP Network Time Distribution: G.8275.1

- Centralized architecture, spans up to 10 nodes
- Boundary clock/1PPS at each node. L2 m/c



PTP Network Time Distribution: G.8275.2

- Centralized architecture, spans up to 10 nodes, L3 Unicast
- Boundary Clock placed only “where required”



Satellite Based (GNSS) Time and Frequency Distribution

Satellite Time Distribution (GNSS)

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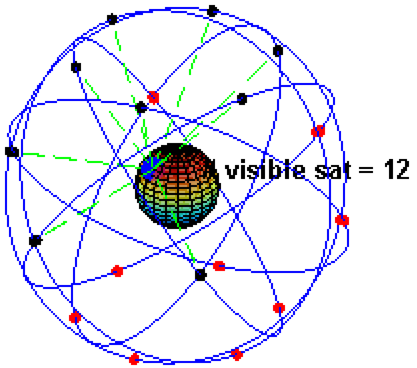
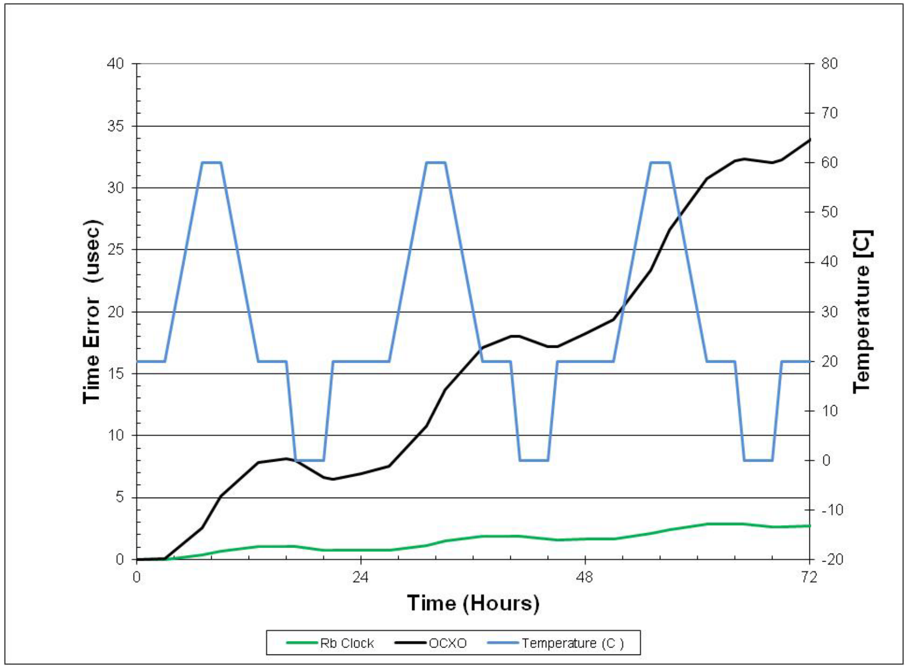
- Time distributed by radio from satellite
- Typical accuracy: < 100ns
- Advantages:
  - Global availability
    (provided there is a clear view of the sky)
  - Accuracy
  - System reliability
- Disadvantages:
  - Clear view of sky may not be available
  - Vulnerability to interference from ground based transmissions
  - Antenna issues – wind, rain, snow, ice, corrosion, bullets...
  - Political issues



How long can you hold a microsecond if GNSS is not available?

- PRC (Primary Reference Clock):
  - Frequency error ≤ 1 x 10^{-11} (G.811 specification)
  - Phase drift up to 1µs in 100,000s (~28 hours)
- Rubidium clock
  - Phase drift under temperature cycling: ~1.5µs in 24 hours
  - Holds 1µs for a few hours
- Good quality OCXO
  - Phase drift under temperature cycling: ~8µs in 24 hours
  - Holds 1µs for a few minutes



Maintaining time between GNSS fixes

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- In urban canyons or in buildings, fixes may be several minutes apart
- Local interference or jamming may temporarily interrupt GNSS service
- Timebase maintained using stable frequency
  – OCXO will maintain 1µs for around 60s (variable temp)
  – SyncE will maintain 1µs phase for around 2000s
  – Rb oscillator will maintain 1µs for nearly 24 hours (variable temp)
- Timebase maintained using PTP
  – PTP will maintain phase indefinitely
  – GNSS time fix can be used to calibrate the asymmetry
  – Measures asymmetry on a "whole of network" basis

In-Building Reception can be Problematic

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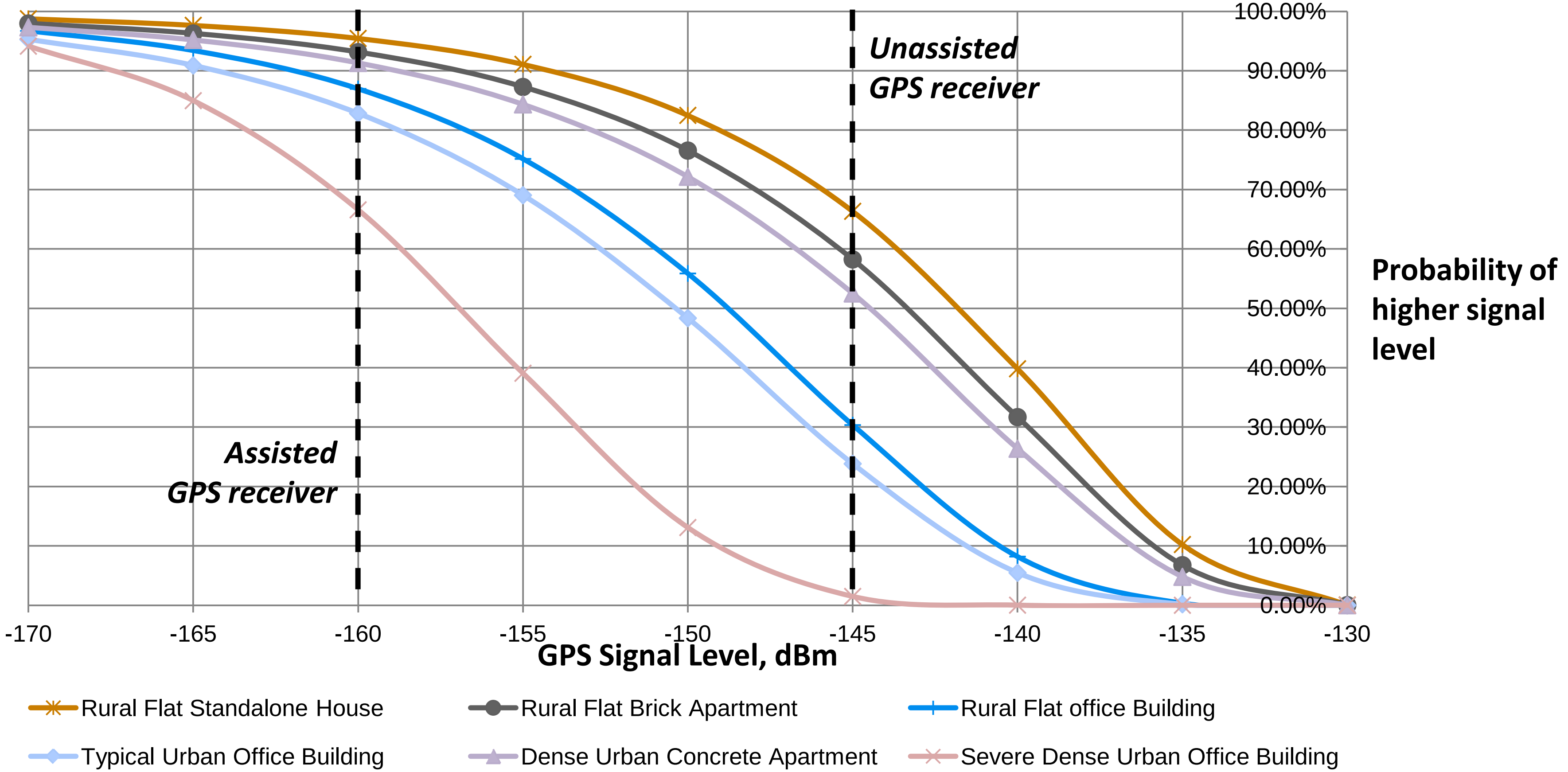
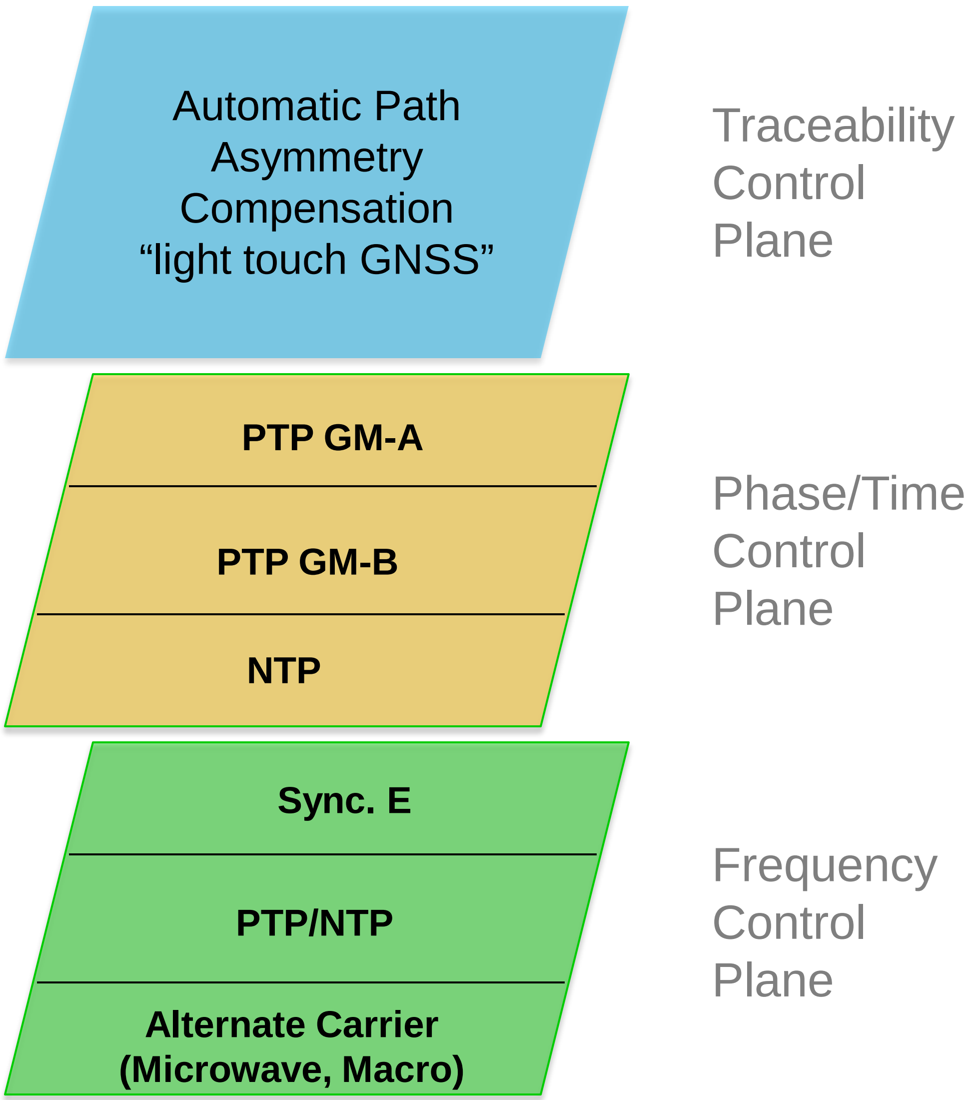
- Signal strength at earth surface around -130dBm
- Buildings may attenuate this by over 40dB



Graph adapted from Small Cell Forum white paper "Femtocell Synchronisation and Location", May 2012

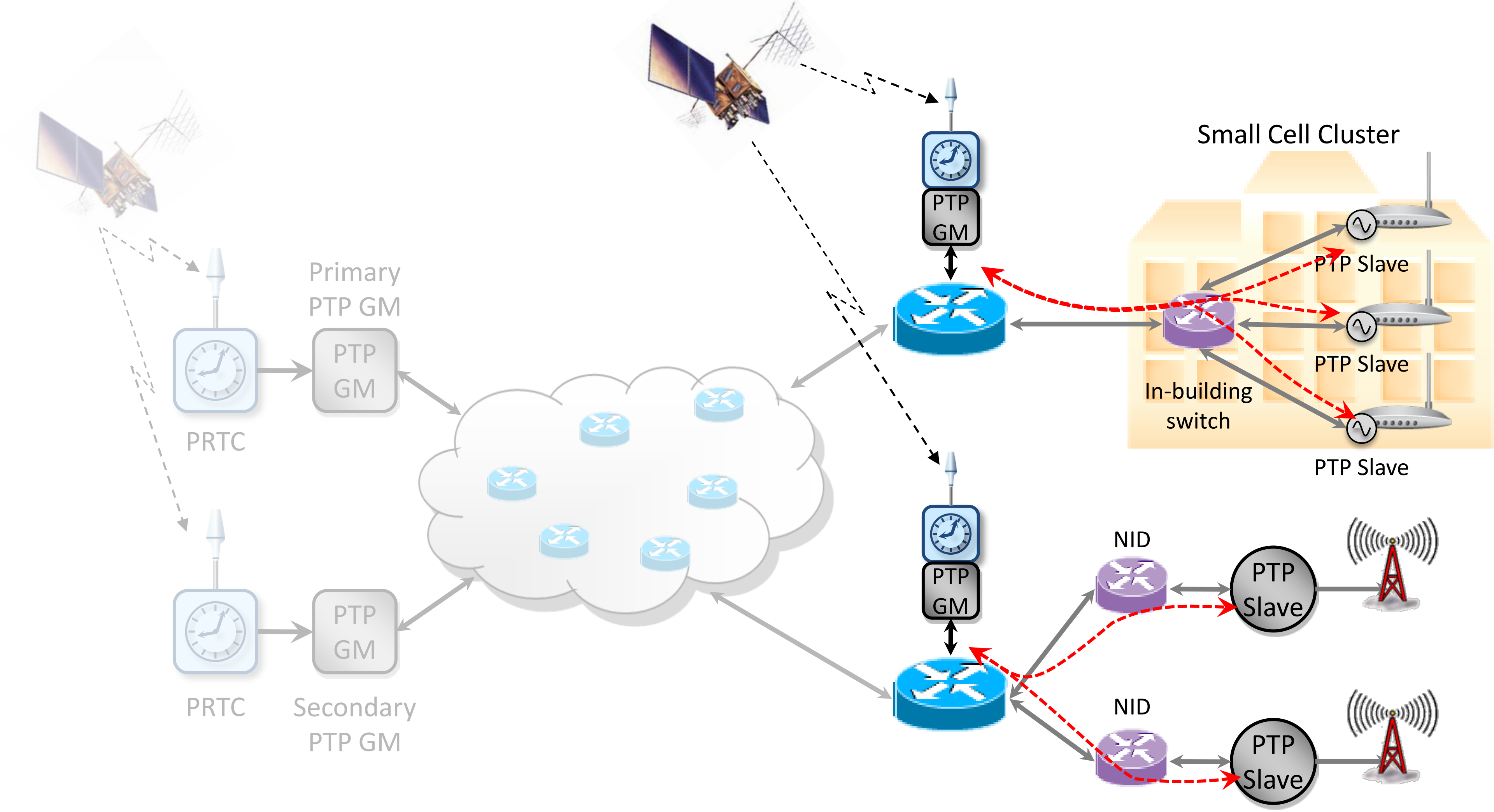
Edgemaster Clock - Multiple Control Planes

- An Edgemaster clock generates traceable time and frequency outputs :
  - Source for Time Control can be different than Frequency Control
  - Frequency control plane stabilizes the local oscillator for enhanced time control.
  - Frequency and Time control operate simultaneously
  - Traceability Control mitigates path asymmetry



Moving Time to the Edge

Solution: Distribute Primary Reference Time Clock to the mobile edge



Edge Packet Network

Access Network

(packet time and frequency distribution)

End Equipment
(e.g. Basestations)

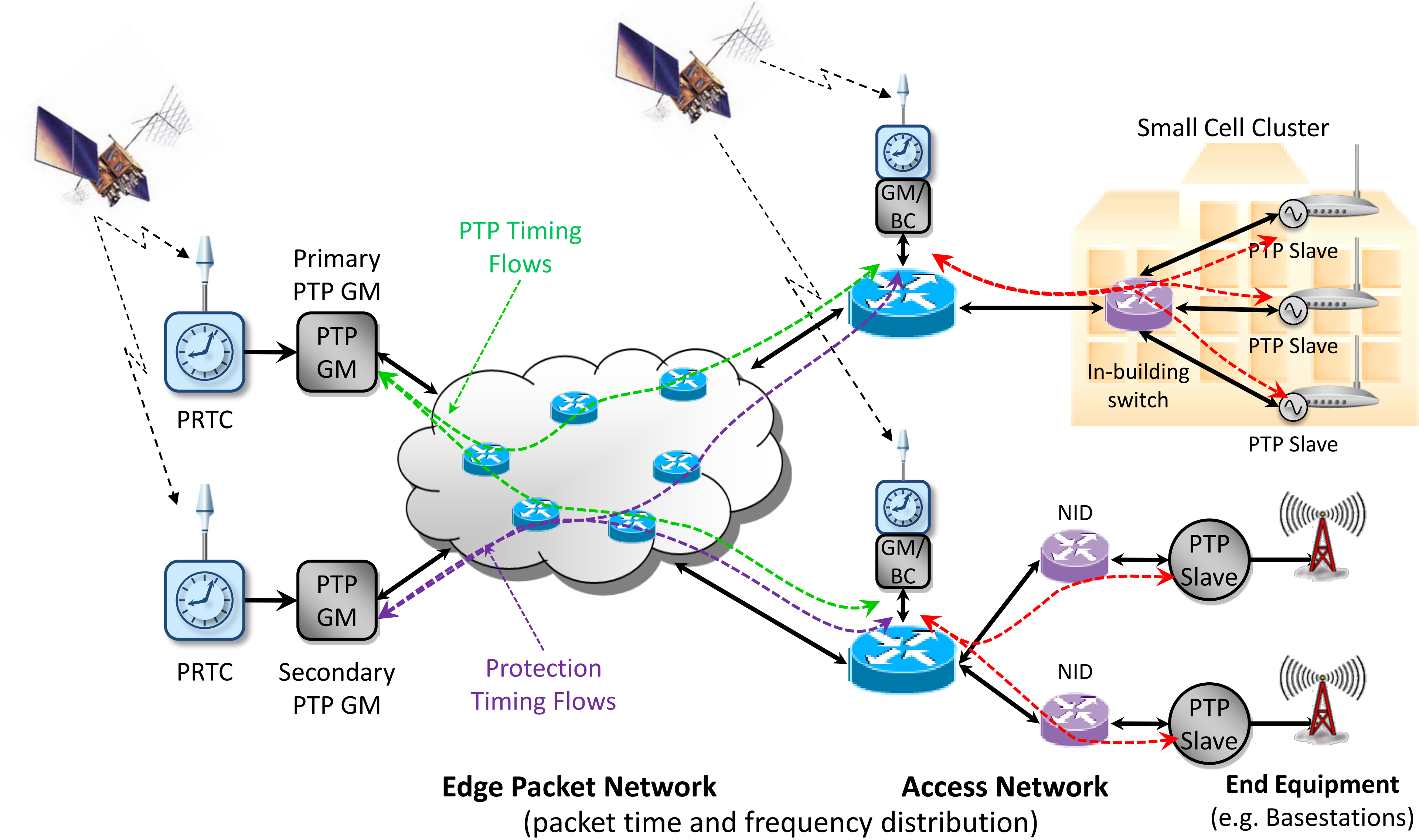
Problem : Path Delay Asymmetry

- Delay asymmetry is the difference between forward path delay and reverse path delay
  - Causes a time offset of half the delay difference
- Budget for time offset:
  - 50ns for each boundary clock (550ns total, including final slave)
  - 250ns for link asymmetry (total of all links)
  - PTP can't estimate this: must be measured
- Measurements on real fibers:
  - Delay difference between fibers in same core varied by up to 200ns per link
  - Caused by length differences in fibers, plus cuts/resplices
- Conclusions
  - Each individual link must be measured and compensated
  - 250ns link asymmetry budget for network is for error in compensation, not the budget for the asymmetry itself

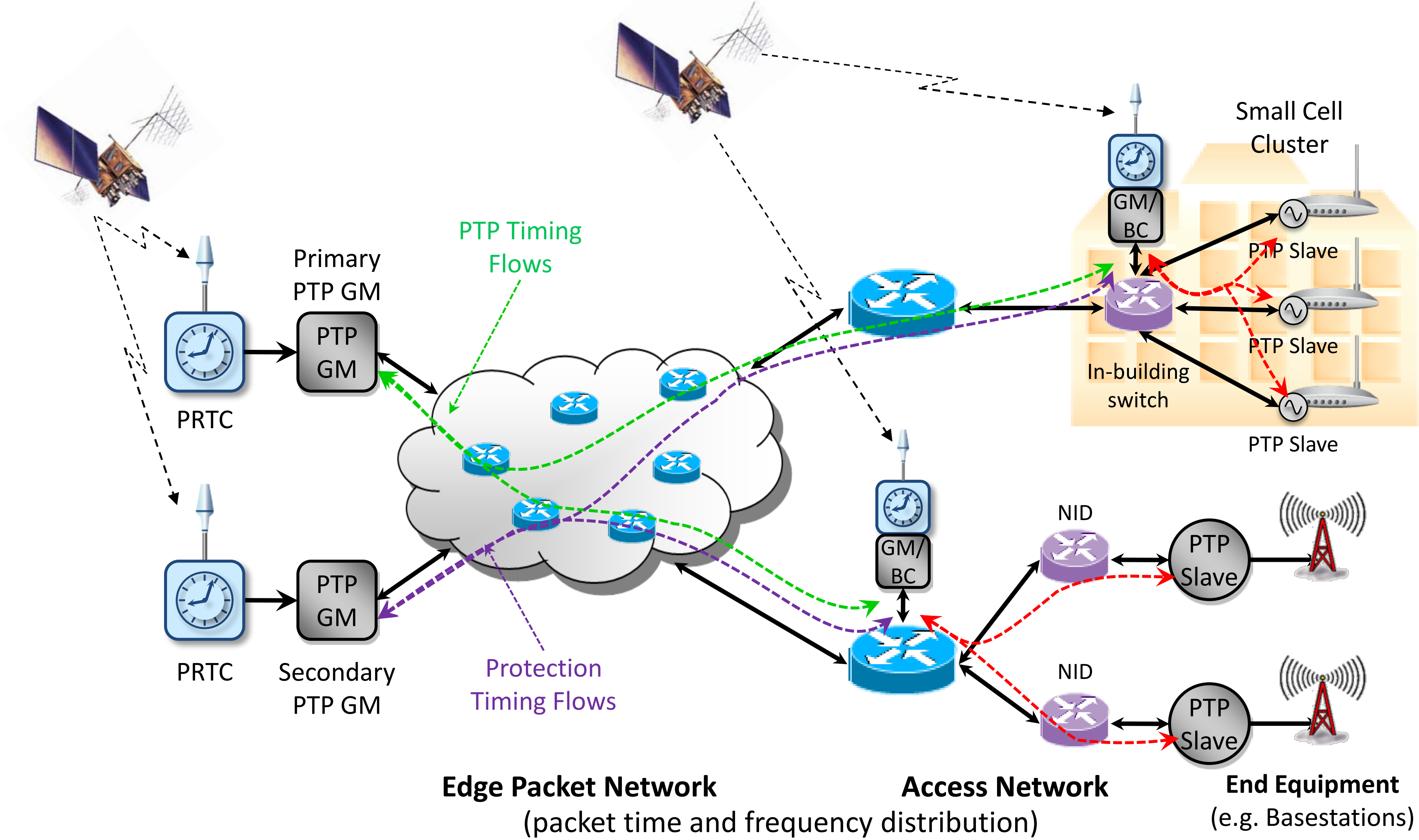
Distribute PRTC to the edge

- Close enough that link asymmetry is not an issue
  - Within a few miles, not hundreds of miles
  - Closest aggregation point that is physically accessible for GNSS
  - Set budget to accommodate the smaller asymmetry value
- In indoor deployments:
  - Use a single antenna on the roof, and distribute time over LAN
  - Alternatively, deploy at aggregation point for multiple small cell clusters
- In outdoor deployments:
  - Place a PRTC at strategic aggregation point for microwave
- Moving PRTC close helps to reduce dynamic time error (noise), as well as constant time error (offset)

Distributed PRTCs with Network Backup



Move PRTCs as close as possible to cells



Examples of Small Cell Sync Services

Mobile Synchronization Requirements

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Application	Frequency Network / Air	Phase	Note
UMTS, LTE FDD Femtocell	100 ppb - 250 ppb air interface	NA	Access is usually DSL , GSON, or Cable
GSM / UMTS / W-CDMA	16 ppb / 50 ppb	NA	
CDMA2000	16 ppb / 50 ppb	± 2.5 to ± 10 µs	
LTE – FDD	16 ppb / 50 ppb	NA	
LTE – TDD	16 ppb / 50 ppb	± 1.5 µs	≤3 km cell radius
		± 5 µs	>3km cell radius
LTE MBMS (LTE-FDD & LTE-TDD)	16 ppb / 50 ppb	± 10 µs	inter-cell time difference
LTE- Advanced	16 ppb / 50 ppb	± 1.5 to ± 5 µs	see table below for detail

LTE-Advanced	Type of Coordination	Phase
eICIC	enhanced Inter-cell Interference Coordination - tight	± 1.5
eICIC	enhanced Inter-cell Interference Coordination - loose	± 5µs
CoMP Moderate	UL coordinated scheduling	± 5 µs
	DL coordinated scheduling	± 5 µs
CoMP Very tight	DL coordinated beamforming	± 1.5 µs
	DL non-coherent joint transmission	± 5 µs
	UL joint processing	± 1.5 µs
	UL selection combining	± 1.5 µs
	UL joint reception	± 1.5 µs

LTE-A covers multiple techniques rather than a single technology.

Not all features will deployed everywhere, leading to differences in real world requirements.

Figures are still in discussion by members of the 3GPP.

Note: Inter-cell coordination times are requirement for distributed time accuracy.

Sync Services for LTE Small Cells

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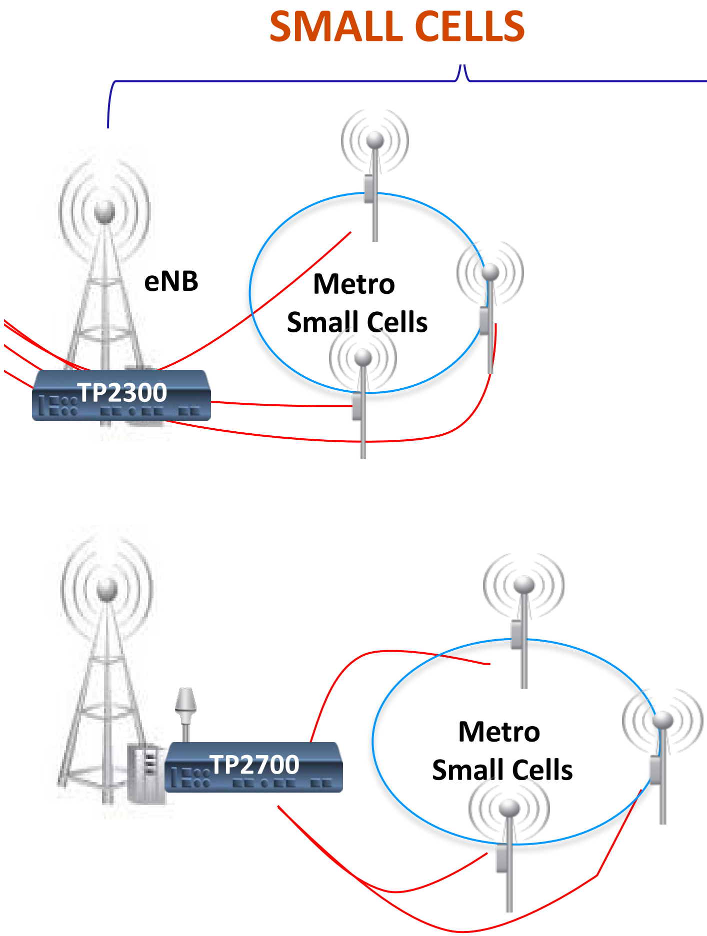
Driving Phase Sync to the Mobile Edge

- Why do we need a different approach in LTE Mobile edge?
- Phase distribution is getting more important, and is moving to the edge.
- LTE networks need more eNB density
  - the use of small cells solves this problem cost effectively
- The small cells sync enables
  - hand off in the hetnet
  - interference reduction between the macro and small cell layer
  - improved coverage and increased LTE spectrum efficiency



eICIC: Enhanced Inter Cell Interference Coordination

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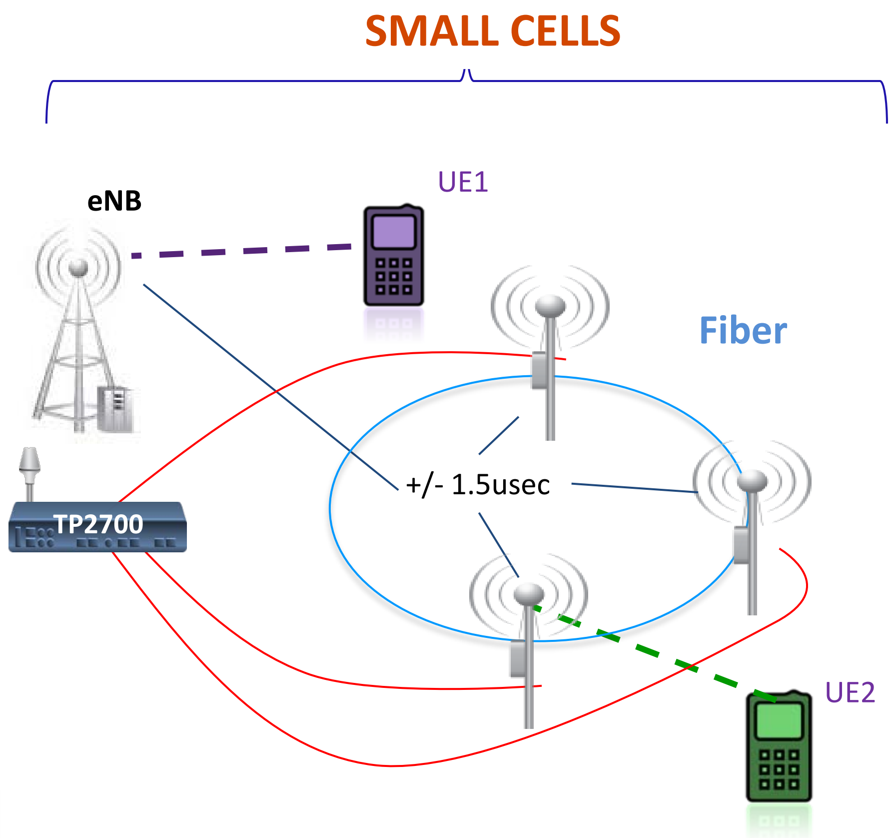
Required for Hetnet in LTE FDD or LTE TDD network

Almost Blank Subframes (ABS) used - requires phase control of the frame

Phase Sync Requirement:

± 1.5 µs inter-cell alignment



		ABS		ABS			ABS		ABS	
0	1	2	3	4	....	41	42	43	44	45
		UE2		Small cell configuration			UE2		Macro configuration	

CoMP: Coordinated Multipoint
MIMO: Multiple Input Multiple Output

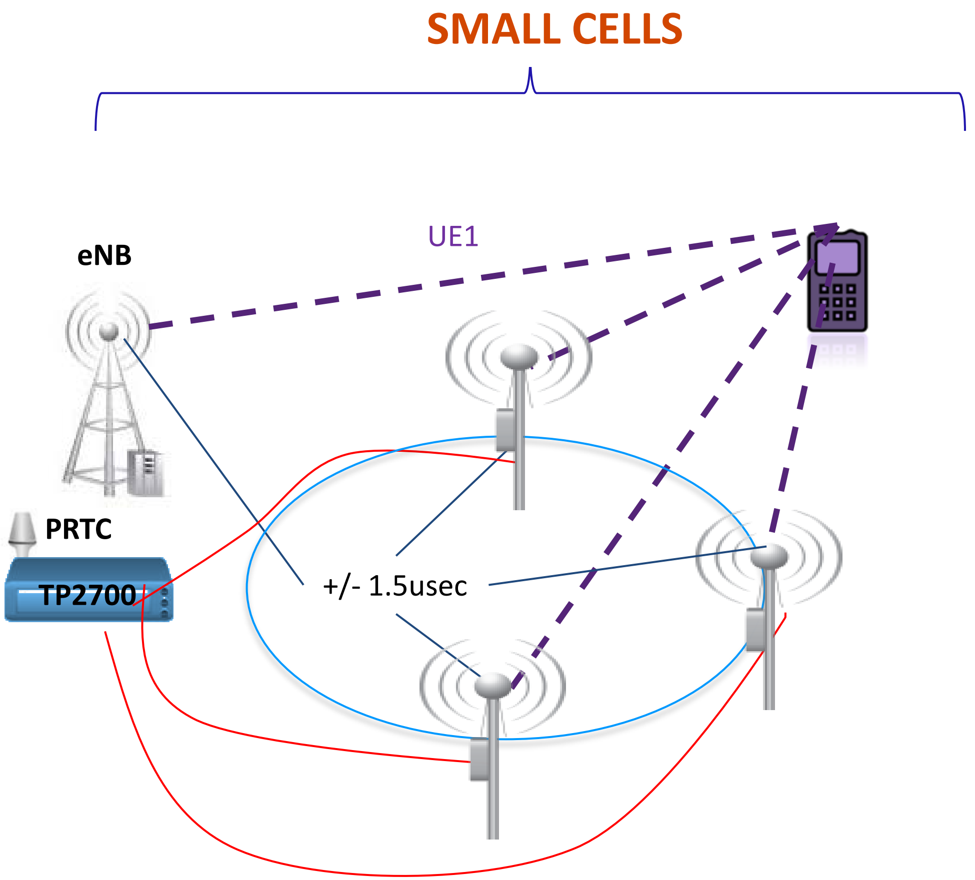
Antenna Management and eNB paging Techniques used to avoid interference and increase efficiency

The UE (Mobile Phone) has connections with multiple eNBs simultaneously

Requires close coordination between the eNB and UE

Phase sync requirement:

$\pm$ 1.5 µs



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Conclusions

Conclusions

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- Asymmetry of network elements and links is the biggest contributor to time error
- Not solved by putting boundary clocks at each node
- Solutions :
  - Manually measure each link and compensate for it
  - Minimise asymmetry by placing PRTC close to the application
  - Automatically calibrate the path, using GNSS reference
- Hybrid techniques address the deficiencies of PTP, SyncE and GNSS
  - Gateway clocks such as the Symmetricom Edgemaster with multi-sync functions create an accurate, robust solution for precise time distribution
  - Small Cell deployments will require a distributed PRTC architecture with advanced gateway clock functions

Thank You

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Network Time and Frequency Distribution

Two-Way Time Transfer Techniques

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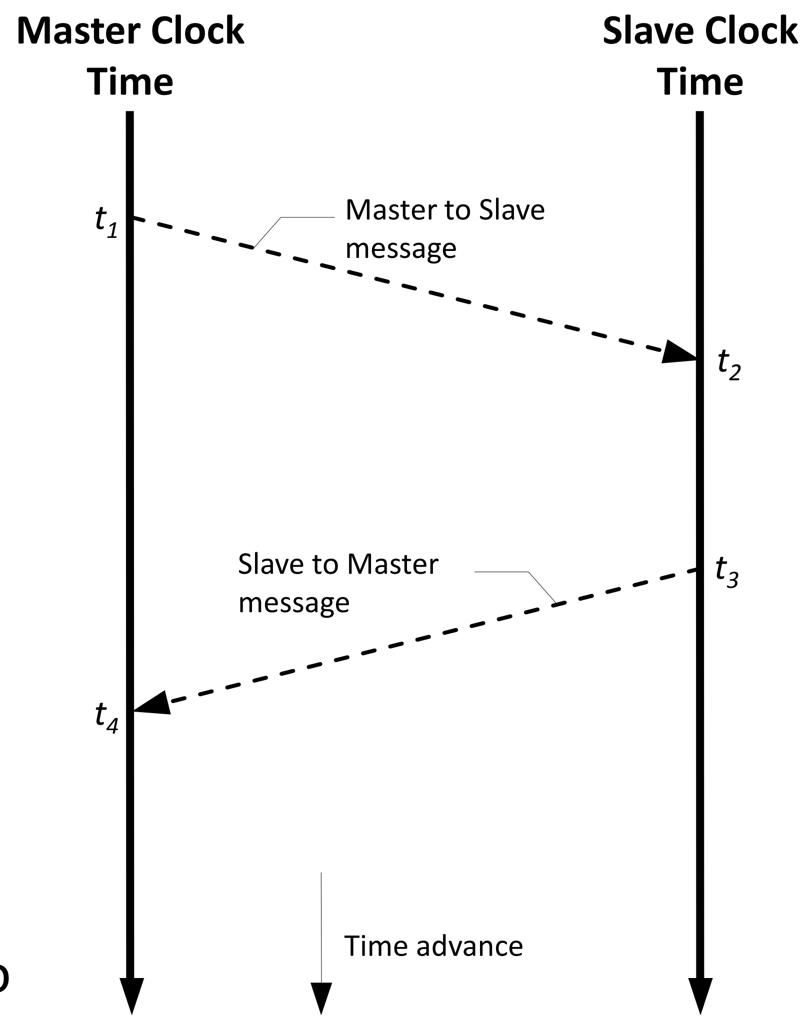
- Basis of most network time distribution mechanisms
  - NTP, PTP, DTI, custom
- Based on a two-way timed message exchange between the master and slave
- Time offset calculation requires all four timestamps:
  - Slave time offset = $\frac{(t_2 - t_1) - (t_4 - t_3)}{2}$
- **Assumes symmetrical delays**
  - i.e. the forward path delay is equal to the reverse path delay



Precision Time Protocol (PTP, IEEE1588)

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- Two-Way Time Transfer over packet networks, using accurate timestamps at the physical interface
- Designed to operate over standard communications networks such as Ethernet and IP in both LAN and WAN environments
- Introduces “on-path timing support” to mitigate variable delay in the network elements
  - Boundary clocks terminate and re-generate timing at each node
  - Transparent clocks add a correction for the delay through each node
- Typical accuracy: depends on size of network
  - Error may not accumulate linearly
  - Doesn’t include asymmetry of link delays

Synchronous Ethernet

- Uses Ethernet bit clock to carry synchronisation signal
- Equivalent performance to conventional physical layer synchronisation
  - Sync signal traceable back to PRC
  - Long term frequency accuracy of 1 part in 10^{11}
- Advantages
  - Stable, accurate frequency reference
  - No need for expensive ovenized crystal at slave clock
- Disadvantages
  - Frequency only, doesn't provide time or phase
  - Requires end-to-end infrastructure to support it