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Synchronisation in Future VF Mobile Networks

Max Gasparroni – VF Group R&D

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vodafone

Ensuring synchronisation for the next generation of VF cellular IP backhaul

CONTENTS

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VF mobile plus strategy

Transform Vodafone from a mobile only to a total communication provider

Key propositions: Mobile Internet, Fixed offering, Mobile Advertising

1

Mobile Internet

Extending traditional Internet interactions to the mobile

Provide faster wireless networks for richer services

GSM GPRS/EDGE	3G WCDMA-FDD	3G + HSDPA	3G + HSPA	NGMN (LTE-WiMAX)
64 – 144 kbps	64 – 384 kbps	0.384 – 4 Mbps	0.384 – 7 Mbps	20+ to > 50 Mbps
2000	2004	2007	2008	2010+

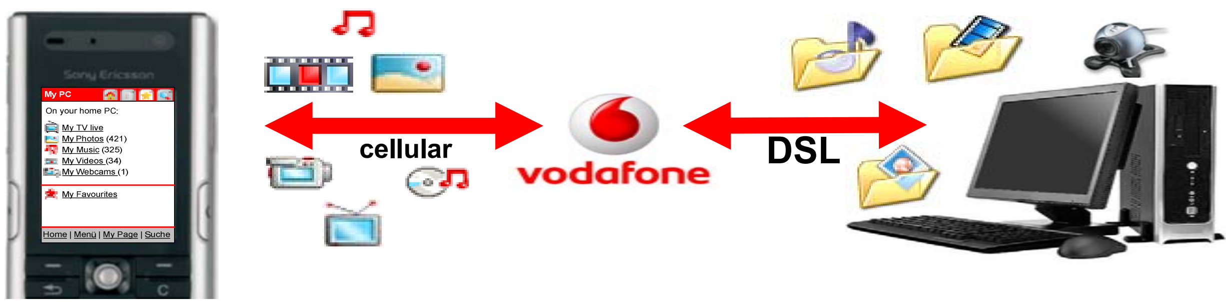
time

VF mobile plus strategy (cont.)

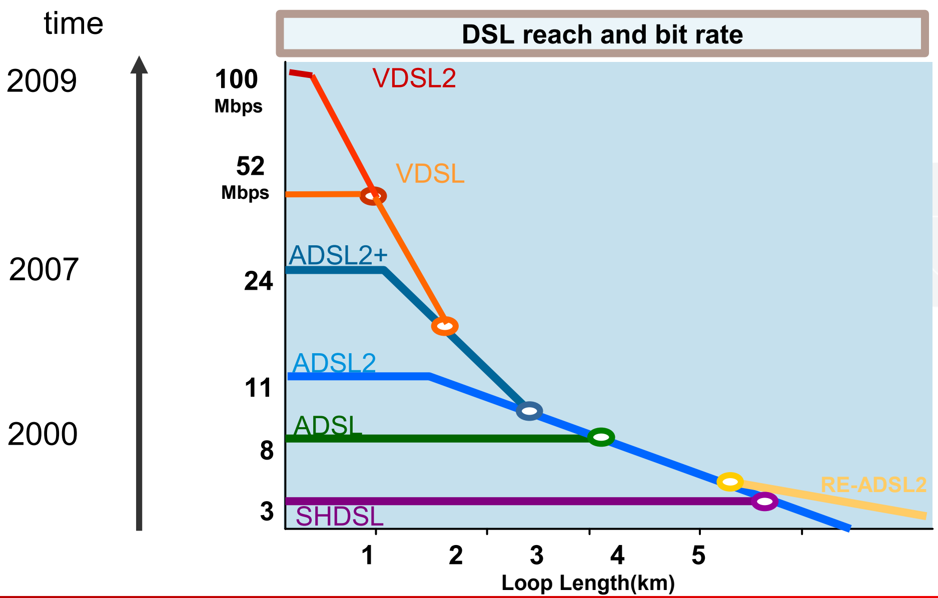
2

DSL Offering
(and PC integration)
Consumer + Enterprise

Integrated media rich services for mobiles and PC



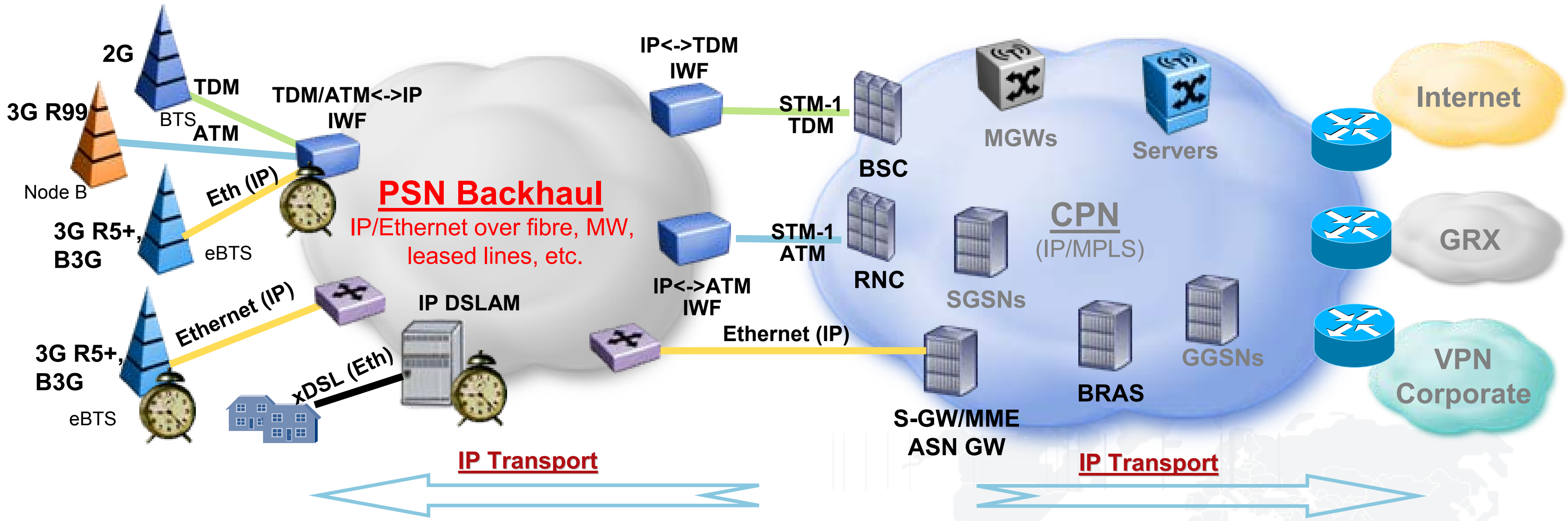
Provide faster fixed connectivity for richer services



Backhaul Challenge - Backhaul convergence towards IP

Mobile Internet and fixed offering will put an enormous pressure on the backhaul network…

Regardless of the 'backhaul end game', a unified transport layer (IP/Ethernet) will enable the opportunistic exploitation of different physical connections available…



The migration from a 'synchronous' circuit-switched (TDM/ATM) to an 'asynchronous' packet-switched (IP/Ethernet) transport creates a 'synchronization' issue for Vodafone…

Critical need to ensure for current and future mobile networks… (future-proof)

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Migration to native IP - Timeframe

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2008 – early 2009 (limited demand)	• Self-build backhaul network expansion (native Ethernet over MW, fibre, etc.) • Backhaul network provisioning for LLU (xDSL) which could be used for cellular backhaul as well • Sporadic native Ethernet connectivity offered by fixed providers as replacement of leased lines
Mid 2009 onwards (extensive demand – network wide)	• Migration of IP/MPLS over existing SDH/PDH infrastructure (POS, ML-PPP) towards native Ethernet • Widespread deployment of Ethernet MW • Extensive native Ethernet connectivity offered by fixed providers as replacement of leased lines

Deploy some 'interim solutions' (based on cost and accuracy requirements) until future-proof solutions reach the required maturity level…

Vodafone involvement in synchronisation

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Why is Vodafone Group R&D involved in synchronisation ?

Global coordination	Avoid duplication in developing technology required by the majority VF OpCos
Economy of scale	Identify a 'common' solution fulfilling current and future requirements of the various VF OpCos (useful in case of network consolidation)
Technology shaping	Work collaboratively with strategic suppliers to make sure the solution meets VF requirements
Technology roll-out	Advice VF OpCos on 'optimal' solutions to deploy (both interim and long-term) and the list of 'preferred' suppliers

Vodafone Group R&D Activities

What is Vodafone R&D doing in synchronisation ?

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1. Sync techniques scouting	• R&D has been engaging with the major players to identify the optimal solution for VF taking into account: - current and future wireless technologies and backhaul connectivity - deployment scenarios (macro, micro, femto) - cost targets
We are here! 2. Technology assessment	• Perform lab tests to assess synchronization performance under 'severe' loading conditions • identify necessary protocol modifications / optimisations / customisations • Disseminate the results to major stakeholders in VF and relevant vendors
3. Live trials	• Engage with VF OpCos to carry out live trials of the identified solution • Test the technology in realistic (not controlled) environment
4. Commercial Engagement	• Assist VF Group Technology and OpCos on commercial aspects (RFP, RFQ)

Synchronization requirements for VF networks

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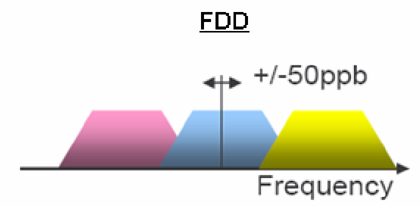
Mobile Networks

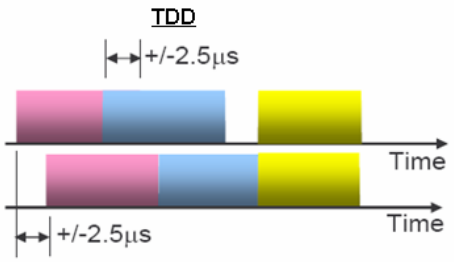
Frequency Sync

- WCDMA **FDD** systems
  - **+/- 50 ppb** (part per billion)
    - +/- 100ppb for pico/femto



Time Sync

- WCDMA **TDD** systems
  - **+/-2.5 µs** (micro second) between base stations is required **(+/- 1.25 µs between ref and BTS)**
    - CDMA 2000: +/-3 µs time alignment
- Mobile WiMAX
  - **< +/-2.5 µs** (**or down to +/- 1.0 µs for some WiMAX profiles**)



Real-Time Applications

APPLICATION	SYNCHRONIZATION REQUIREMENT
Voice	< 32 ppm (part per million)
Ethernet Best Effort	< 100 ppm (part per million)
Two-way Video	< 50 ppb (part per billion)
One-way Video MPEG	< 500 ppb (part per billion)
One-way Video HDTV	< 100 ppb (part per billion)
One-way Video IPTV	< 100 ppb (part per billion)

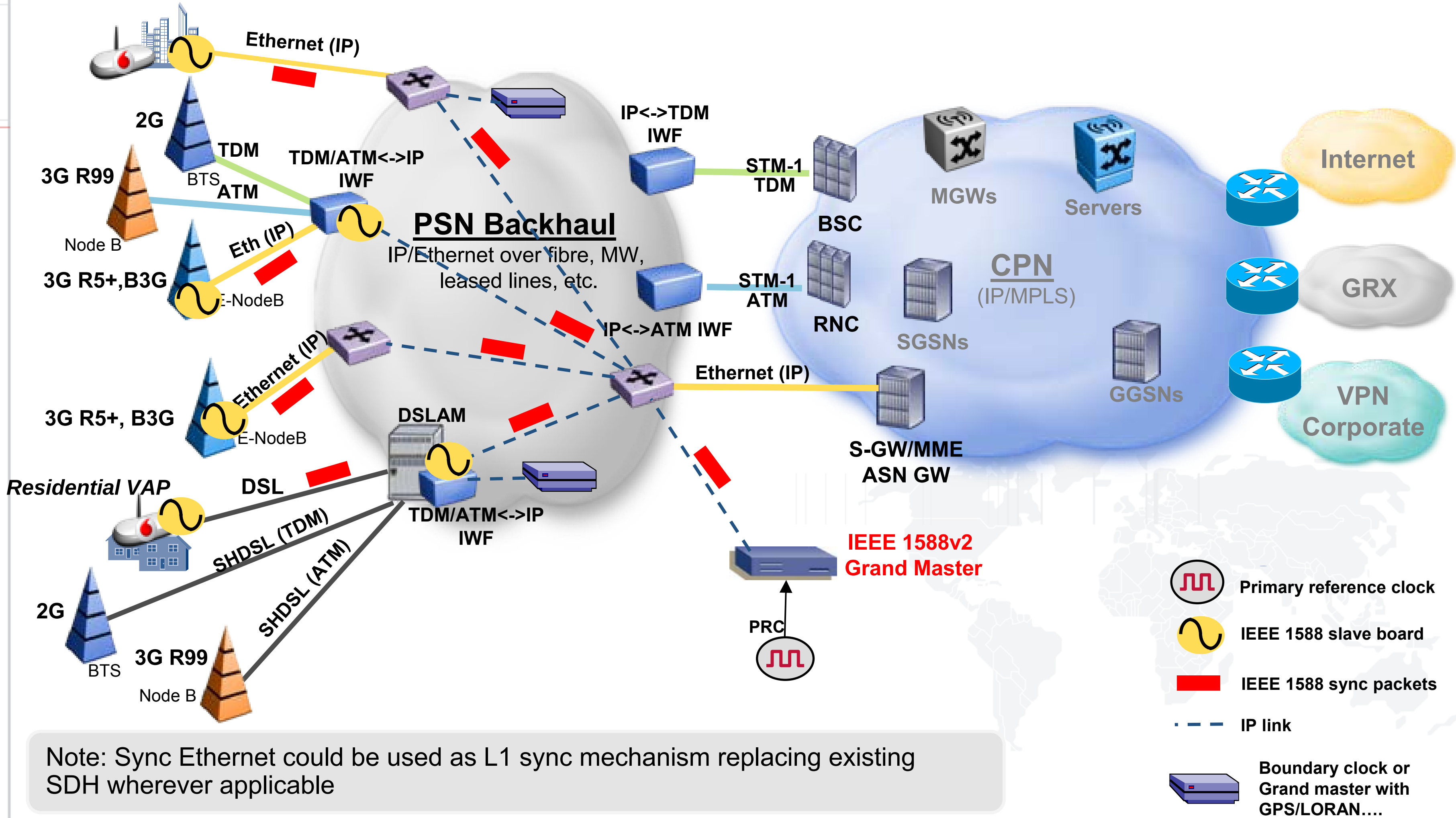
- Frequency Synchronisation: **+/- 50 ppb Accuracy** (GSM, 3G and LTE FDD systems)
- Phase Synchronisation (relative-time sync): **+/- 2.5 µs Time Accuracy** (TDD systems - including WiMAX) -> could be down to **+/- 1.0 µs** for some WiMAX profiles

1. Sync techniques scouting

GPS receiver at every node ☹	↑ Deliver frequency and time (up to 50ns accuracy claimed) ↓ Not always viable (indoor cells) ↓ Expensive oscillators required ($500) for periods of unavailability (not 99.999% solution)
Network synchronous Sync Ethernet ☺	→ Use the PHY clock from bit stream (similar to SDH/PDH), each node recovers clock ↓ Only deliver frequency and not phase ↑ Independent from network load ↑ Represent an excellent SDH/PDH replacement option -> viable 'interim' solution
Packet –based In-band synchronization (adaptive clock recovery) ☹	→ The clock is reconstructed using the packet interarrival rate ↑ Inexpensive solution ↓ Subjected to network load conditions, not 'always-on' and deliver frequency (not phase) ↑ Could represent a viable 'interim' solution only in certain scenarios
Packet –based Out-of-band synchronization ☺	→ Clock information is transmitted via dedicated timing packets (master <-> slave) ↑ 'Always-on' solution (even without traffic data) ↑ Ubiquitous solution (works over any transport technology) ↑ Can deliver frequency and phase (FDD and TDD systems) ↑ Major protocols: ***IEEE 1588v2***, IETF NTP version 4

IEEE 1588v2 represents the most promising 'long-term' solution (in conjunction with Sync Eth)

1. Sync techniques scouting - IEEE 1588v2 as ubiquitous sync solution



Note: Sync Ethernet could be used as L1 sync mechanism replacing existing SDH wherever applicable

2. Technology Assessment - IEEE 1588v2 lab tests

Phase I – Jul 2006 -> Jan 2007 (completed)

Objective	Initial assessment of IEEE 1588v2 accuracy in delivering **frequency**
Backhaul	IP/MPLS network with Ethernet connectivity
Equipment	IEEE 1588v2 - Semtech; Reference clock, data analysis – Horsebridge and Oscilloquartz; IP/MPLS backbone, traffic generators - Tellabs

Phase II – Jul 2007 -> Oct 2007 (completed)

Objective	IEEE 1588v2 accuracy in delivering **frequency and phase (relative time)**
Backhaul	IP/MPLS network with Ethernet connectivity
Equipment	IEEE 1588v2 - Semtech; Reference clock, data analysis - Symmetricom; Remote sync monitoring systems - Chronos; IP/MPLS backbone, traffic generators – Tellabs

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2. Technology Assessment - IEEE 1588v2 lab tests (cont.)

Phase III – Oct 2007 -> Dec 2007 (ongoing)

- **Objective**: IP DSLAM synchronisation with IEEE 1588v2
- **Backhaul**: SHDSL for E1 over copper
- **Equipment**:
  - IEEE 1588v2 - Semtech
  - Reference clock, data analysis - Symmetricom
  - Remote sync monitoring systems - Chronos
  - IP DSLAM – Alcatel-Lucent
  - IP/MPLS backbone, traffic generators – Tellabs/Alcatel-Lucent
  - SHDSL modems with NTR support – RAD data communications

Phase IV – Jan 2008 -> June 2008 (to be started)

- **Objective**: IEEE 1588v2 **frequency and phase** accuracy with various backhaul configs
- **Backhaul**: IP/MPLS, Carrier Ethernet, MW, GPON, xDSL, etc.
- **Equipment**:
  - IEEE 1588v2, reference clock, data analysis – Brilliant telecom
  - Backhaul (various tx technologies) – Nokia Siemens Networks

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2. Technology Assessment - IEEE 1588v2 lab tests

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Phase II – Jul 2007 -> Oct 2007

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  - Remote sync monitoring systems - Chronos
  - IP/MPLS backbone, traffic generators – Tellabs

Lab tests – Phase I testbed

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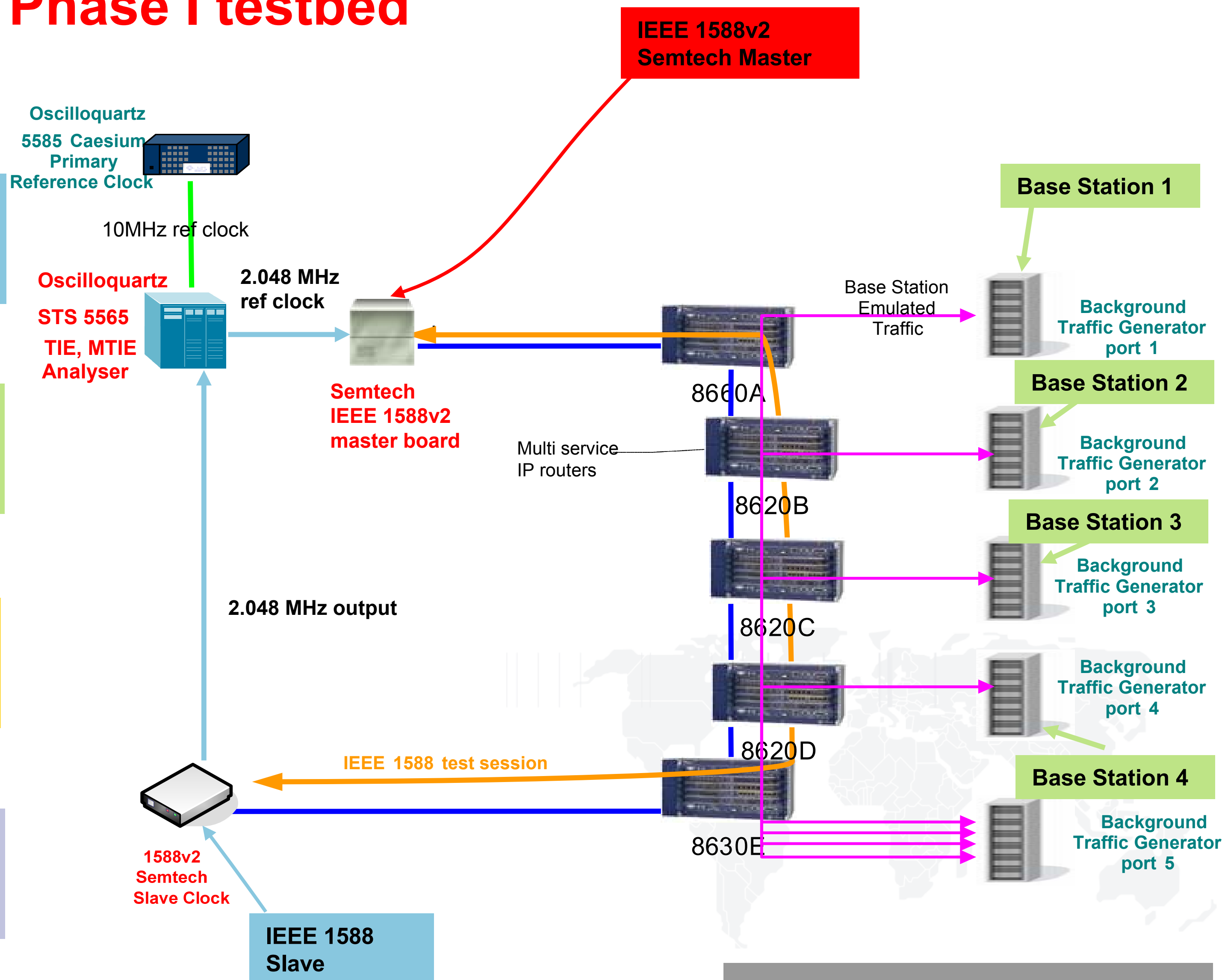
Semtech
IEEE 1588v2 chipset and master clock

Horsebridge
System Integrator

Tellabs
IP/MPLS backbone

Oscilloquartz
Reference clock and data analysis



Frequency accuracy is measured

Lab tests – Phase I traffic scenarios

- Frequency accuracy measured

Different Levels of Constant Traffic	• 20%, 50%, 80%, 90% and 100% of network capacity. (QoS was necessary for the 100% case. For all other cases, tests passed without QoS)	Yellow
Bursty Traffic Modulation	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for periods of 5 seconds. The time between consecutive heavy bursts will be set at 2, 5 and 10 seconds randomly	Green
On/Off Traffic Modulation	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for one hour, then 0% for the next hour, then 75% again for next hour, and so on	Green
Ramp Traffic Modulation	• Generate constant traffic at 10% of network and on top add 75% of traffic in 2.5% increments every 1 minute. Once reached the 75% mark, start decreasing the traffic by 2.5% decrement (again every 1 minute)	Red
Routing Change	• Bypass two MULTI SERVICE ROUTERS switches for a period of time and then restore. The period be in the order of 1000 seconds	Green
Network Overload	• Overload the network by adding up to 90% of network capacity (in addition to the 10% of constant traffic) for periods of 10, 100 and 1000 seconds. (QoS necessary for this test)	Yellow
Network Outages	• Break the network connection for various periods of time (e.g. 10, 100 and 1000 seconds) and restore	Green

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Phase I Lab tests conclusions

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1 IEEE 1588v2 delivers good performance for most of test scenarios

2 Enhancements to 1588v2 slave algorithm necessary to cope with Ramp Scenario (likely to happen in real networks)

3 IEEE 1588v2 packets need to be prioritized (i.e. QoS support) if network overload conditions are likely in the deployed backhaul infrastructure

4 Further work is necessary to assess/improve performance:

- With different routers manufacturers and backhaul infrastructures
- With different IEEE 1588v2 chipsets
- To test phase alignment as well as frequency accuracy

2. Technology Assessment - IEEE 1588v2 lab tests

Phase I – Jul 2006 -> Jan 2007

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- **Backhaul**: IP/MPLS network with Ethernet connectivity
- **Equipment**:
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  - IP/MPLS backbone, traffic generators - Tellabs

Phase II – Jul 2007 -> Oct 2007

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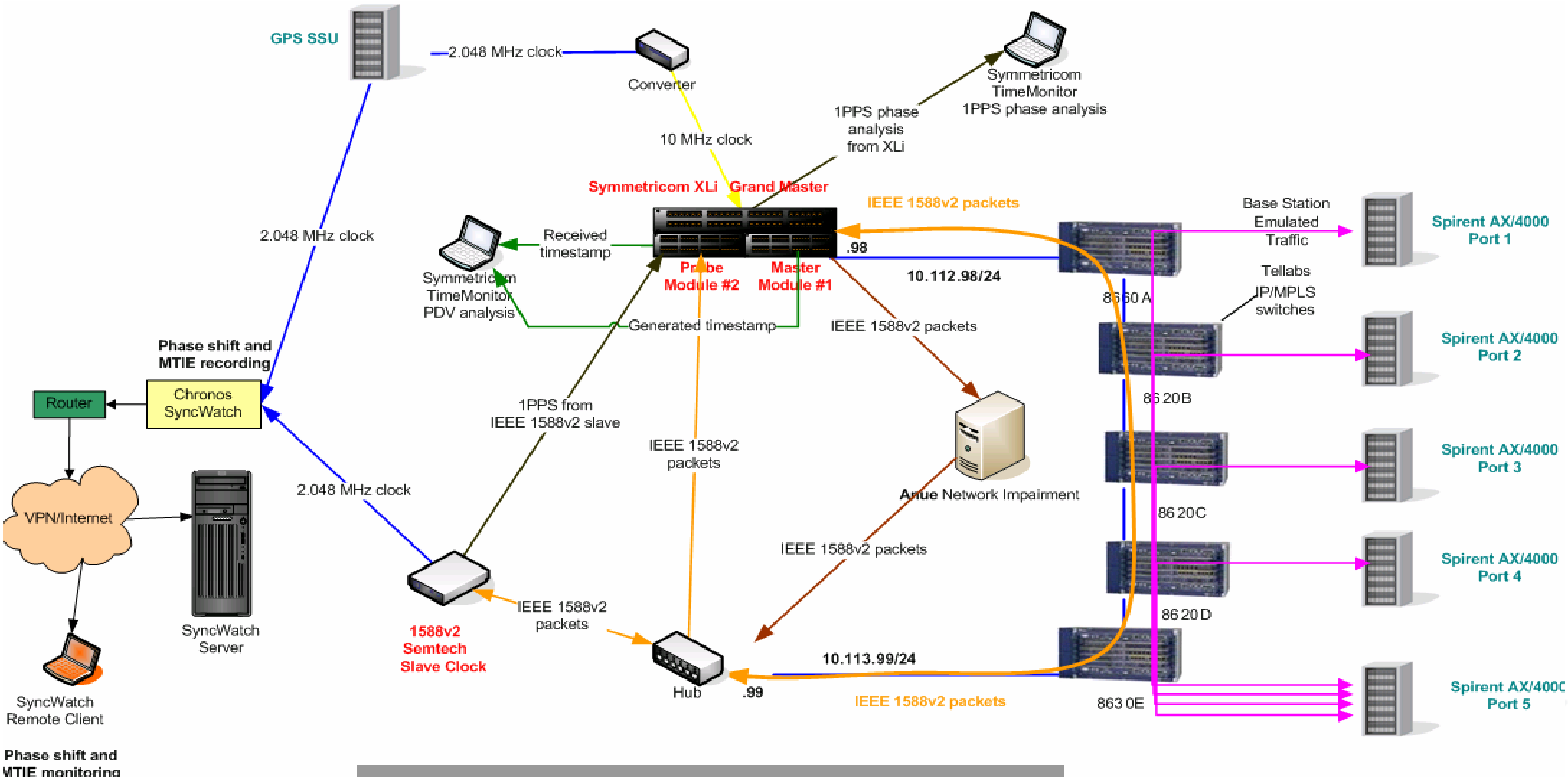
Lab tests – Phase II testbed

Symmetricom Timing master and data analysis	Semtech IEEE 1588v2 chipset	Chronos Remote sync monitoring systems	Tellabs IP/MPLS backbone



Phase alignment and Frequency accuracy are measured

Lab tests – Phase II traffic scenarios

- Phase and Frequency accuracy measured

Different Levels of Constant Traffic	• 20%, 50% and 80%, 90% and 100% of network capacity. (inconsistent behaviour for 100% traffic, with and without QoS, which needs further work)
Bursty Traffic	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for periods of 5 seconds. The time between consecutive heavy bursts will be set at 2, 5 and 10 seconds randomly.
On/Off Traffic	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for one hour, then 0% for the next hour, then 75% again for next hour, and so on
Ramp Traffic	• Generate constant traffic at 10% of network and on top add 75% of traffic in 2.5% increments every 1 minute. Once reached the 75% mark, start decreasing the traffic by 2.5% decrement (again every 1 minute)
Routing Change	• Bypass two Ethernet switches for a period of time and then restore. The period be in the order of 1000 seconds. (The IEEE1588 fails if a second routing change topology happens whilst slave still in holdover and the new PDV higher)
Network Overload	• Overload the network by adding up to 90% of network capacity (in addition to the 10% of constant traffic) for periods of 10, 100 and 1000 seconds. There is lack of improvement with QoS. (Difference from phase I possibly due to different 1588 packet size and rate)
Network Outages	• Break the network connection for various periods of time (e.g. 10, 100 and 1000 seconds) and restore.
G.8261 Ramp Traffic	• Generate constant traffic at 20% of network capacity (20% DL and 8.6% UL) and on top add 60% of traffic in 1% increments every 12 minutes. Once reached the 80% mark (i.e. after 12 hours), start decreasing the traffic by 1% decrement (again every 12 minute)
G.8261 Network Congestion	• Start with 40% of network load. After a stabilization period, increase network disturbance load to 100% for 10s, then restore. Repeat with a congestion period of 100s
Susceptibility and Immunity	• Perform susceptibility and immunity tests by degrading the recorded PDV profile (using ANUE network emulator) and see when the IEEE 1588v2 slave clock breaches the target synchronization masks -> postponed to future tests

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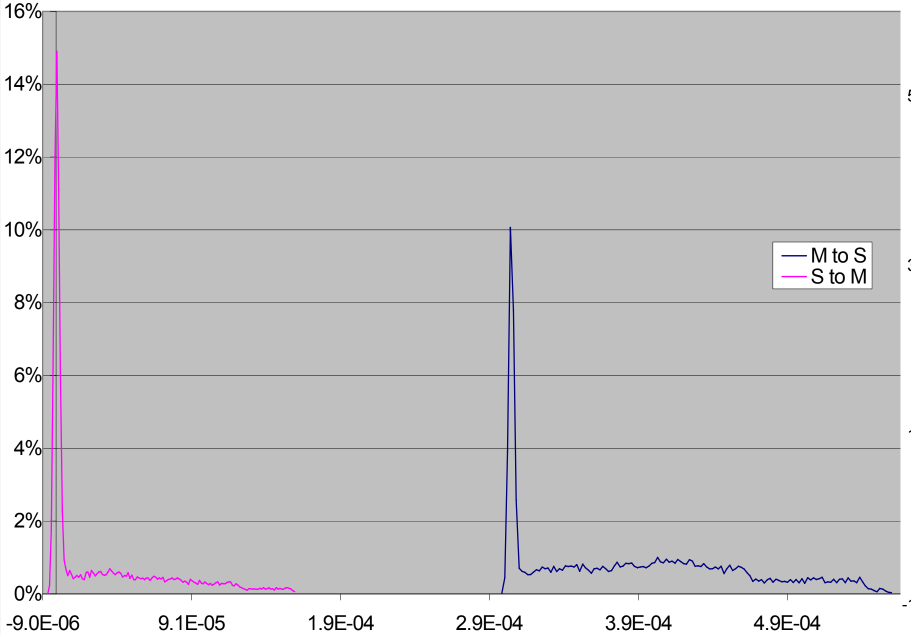
Phase II results – Ramp Traffic modulation

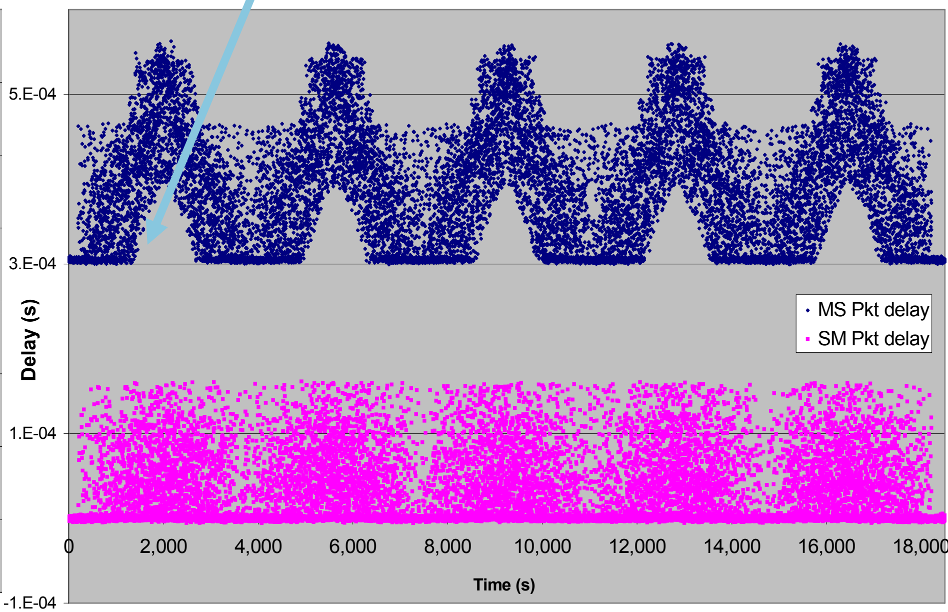
Ramp Traffic Modulation

- Generate constant traffic at 10% of network and on top add 75% of traffic in 2.5% increments every 1 minute. Once reached the 75% mark, start decreasing the traffic by 2.5% decrement (again every 1 minute)

Recorded PDV distribution and scatter



Floor movement starts above 50% load



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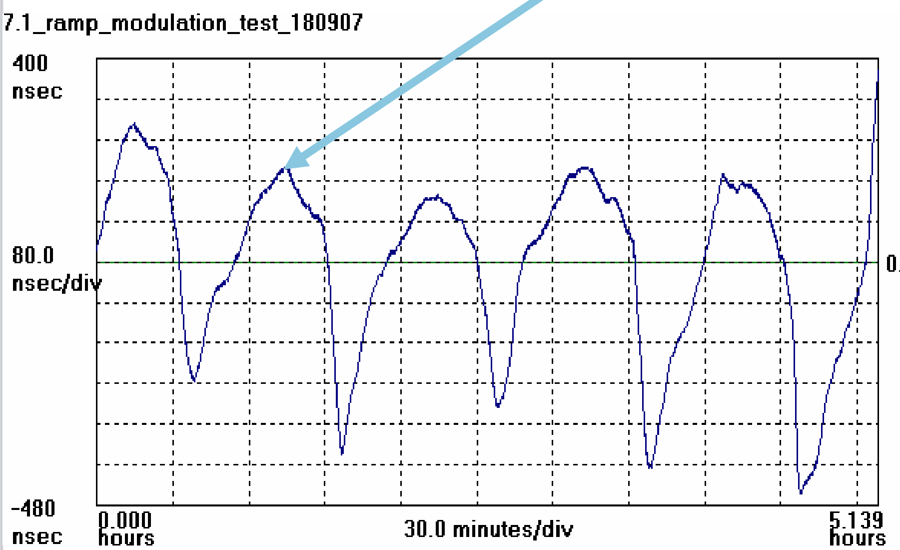
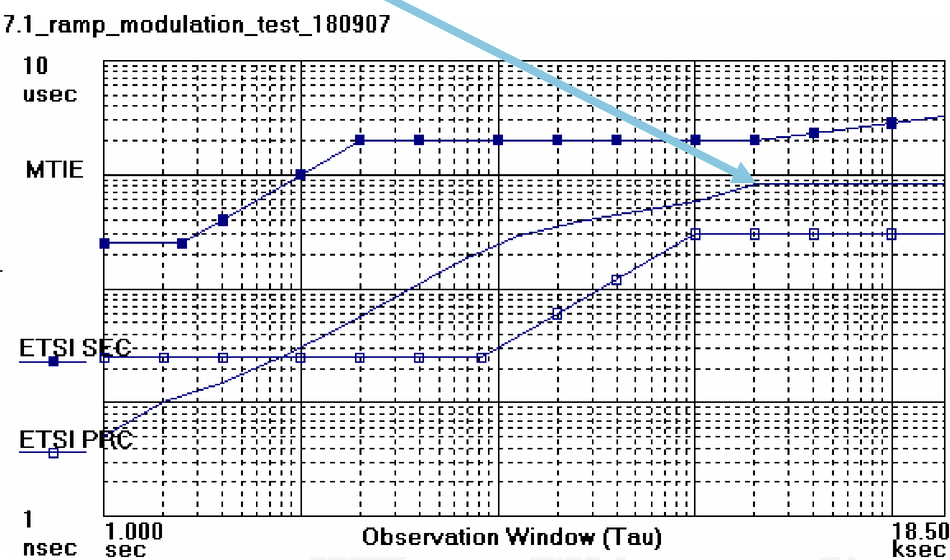
Phase II results – Ramp Traffic modulation (cont.)

Phase and MTIE

<1 µs phase error (under E1 sync mask)





Semtech improved algorithm can now cope with packet delay floor movement…

Phase II Lab tests conclusions

1. IEEE 1588v2 delivers good performance for most of test scenarios considering both **frequency** and **phase** alignment

2. Semtech improved slave algorithm can now cope with packet delay 'floor movement' (experienced with ramp traffic)

3. Enhancements to 1588v2 slave algorithm necessary to cope with big and longer than 100s step changes scenarios with and without QoS support (unlikely to happen in real networks)

4. Test results show that the Sync packet data rate (128, 64, 32, 16) does not make a huge impact on performance

2. Technology Assessment - IEEE 1588v2 lab tests

Phase III – Oct 2007 -> Dec 2007

- **Objective**: IP DSLAM synchronisation with IEEE 1588v2
- **Backhaul**: SHDSL for E1 over copper
- **Equipment**:
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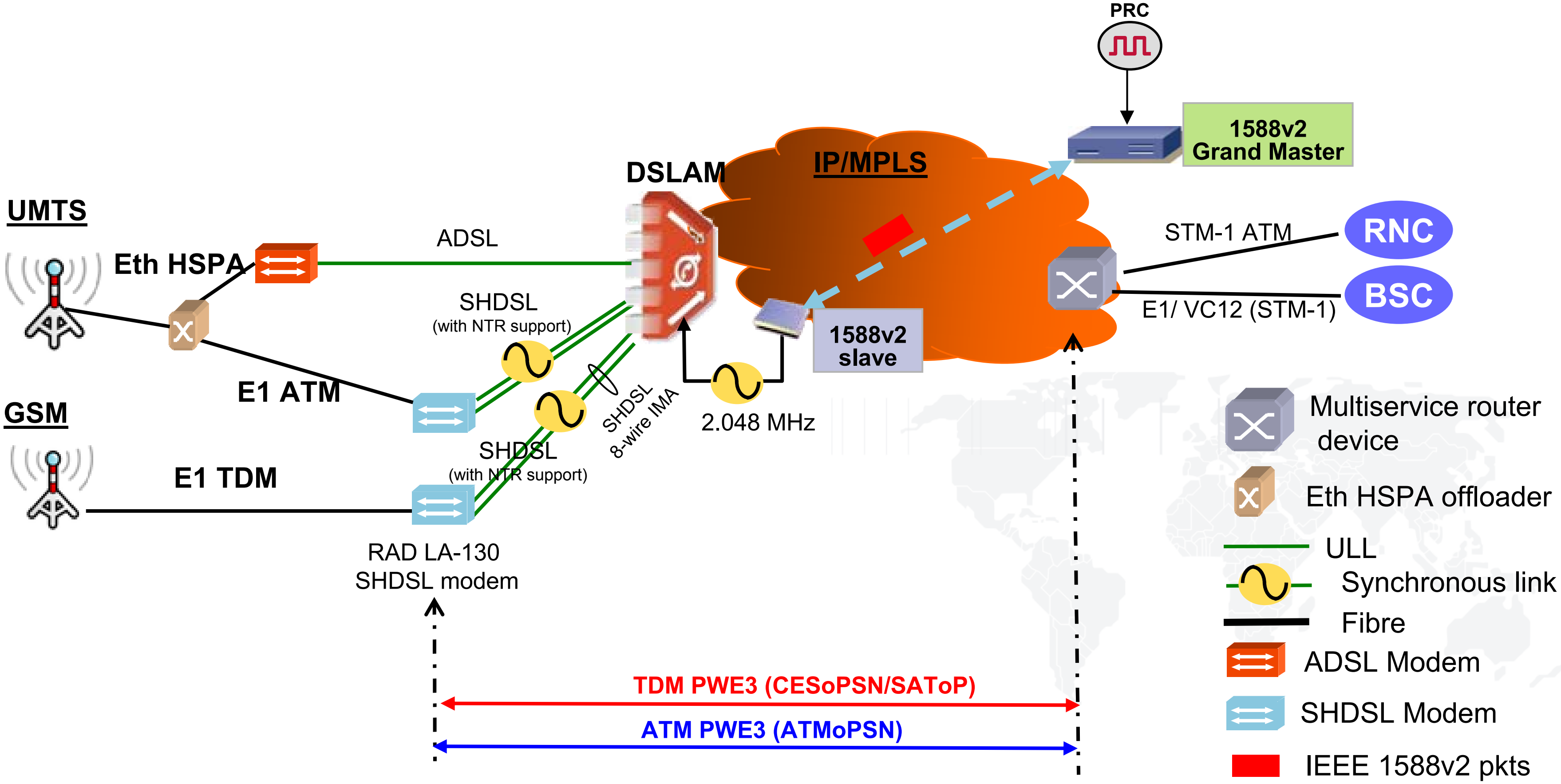
Phase IV – Jan 2008 -> June 2008

- **Objective**: IEEE 1588v2 **frequency and phase** accuracy with various backhaul configs
- **Backhaul**: IP/MPLS, Carrier Ethernet, MW, GPON, xDSL, etc.
- **Equipment**:
  - IEEE 1588v2, reference clock, data analysis – Brilliant telecom
  - Backhaul (various tx technologies) – Nokia Siemens Networks

Phase III - IP DSLAM synchronisation with IEEE 1588v2
High level diagram

Assess whether IEEE 1588v2 provides a synchronization solution for the tactical usage of xDSL to backhaul macro cellular traffic (SHDSL to supply E1 over copper twisted pairs)

Compliance with the E1 sync mask will enable VF to deploy IEEE 1588v2 instead of GPS receivers at each LLU DSLAM (with evident cost benefits)

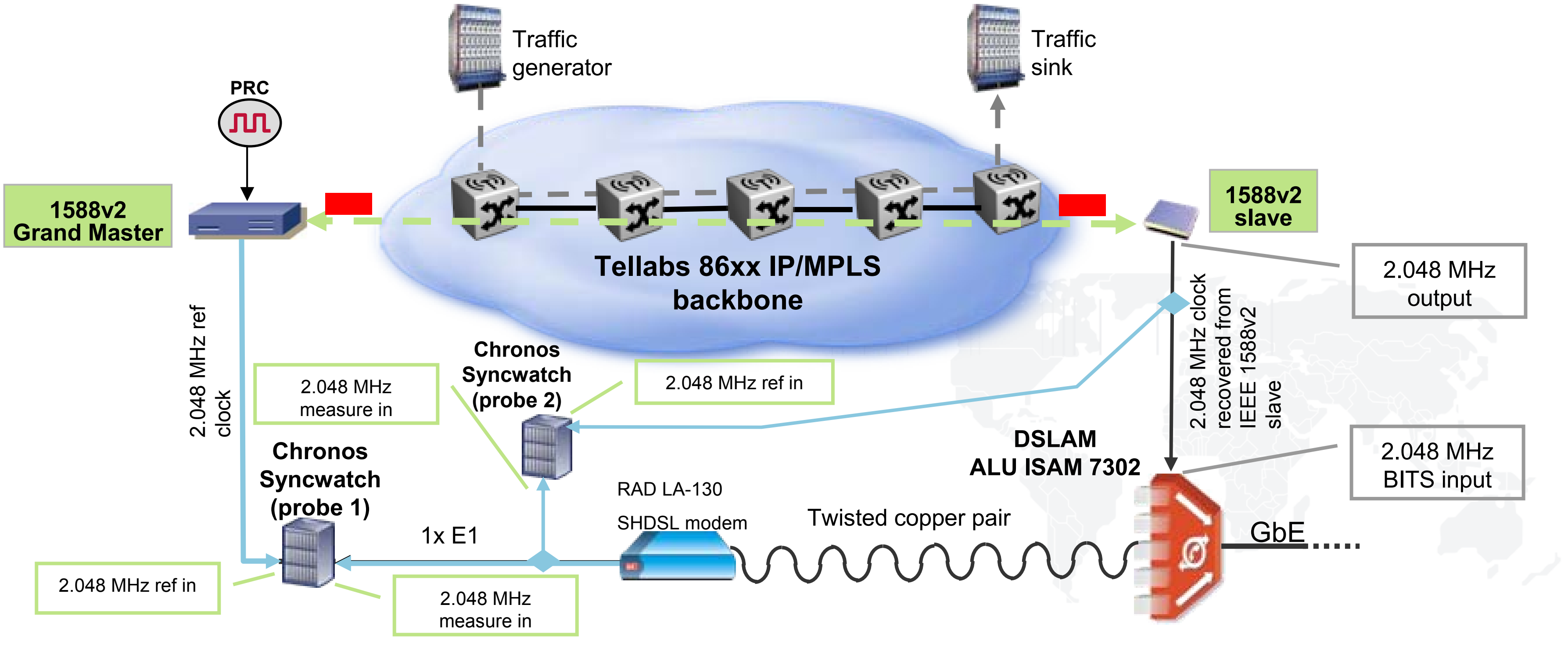


Phase III - IP DSLAM synchronisation with IEEE 1588v2
Stage 1 test setup

No traffic is sent over the E1 SHDSL link

Frequency accuracy achieved at E1 link after SHDSL measured against G.823 (E1) sync and traffic masks

NTR configured over SHDSL



Lab tests – Phase III traffic scenarios Stage 1

- Frequency accuracy of the E1 link measured
  - _ Unloaded E1 link
- Only a subset of tests run so far…

Different Levels of Constant Traffic	• 20%, 50% and 80% of network capacity. 100% load not tested
Bursty Traffic	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for periods of 5 seconds. The time between consecutive heavy bursts will be set at 2, 5 and 10 seconds randomly.
On/Off Traffic	• Generate constant traffic at 10% of network and on top add bursts of traffic at 75% of network capacity for one hour, then 0% for the next hour, then 75% again for next hour, and so on
Ramp Traffic	• Generate constant traffic at 10% of network and on top add 75% of traffic in 2.5% increments every 1 minute. Once reached the 75% mark, start decreasing the traffic by 2.5% decrement (again every 1 minute)
G.8261 Ramp Traffic	• Generate constant traffic at 20% of network capacity (20% DL and 8.6% UL) and on top add 60% of traffic in 1% increments every 12 minutes. Once reached the 80% mark (i.e. after 12 hours), start decreasing the traffic by 1% decrement (again every 12 minute2)

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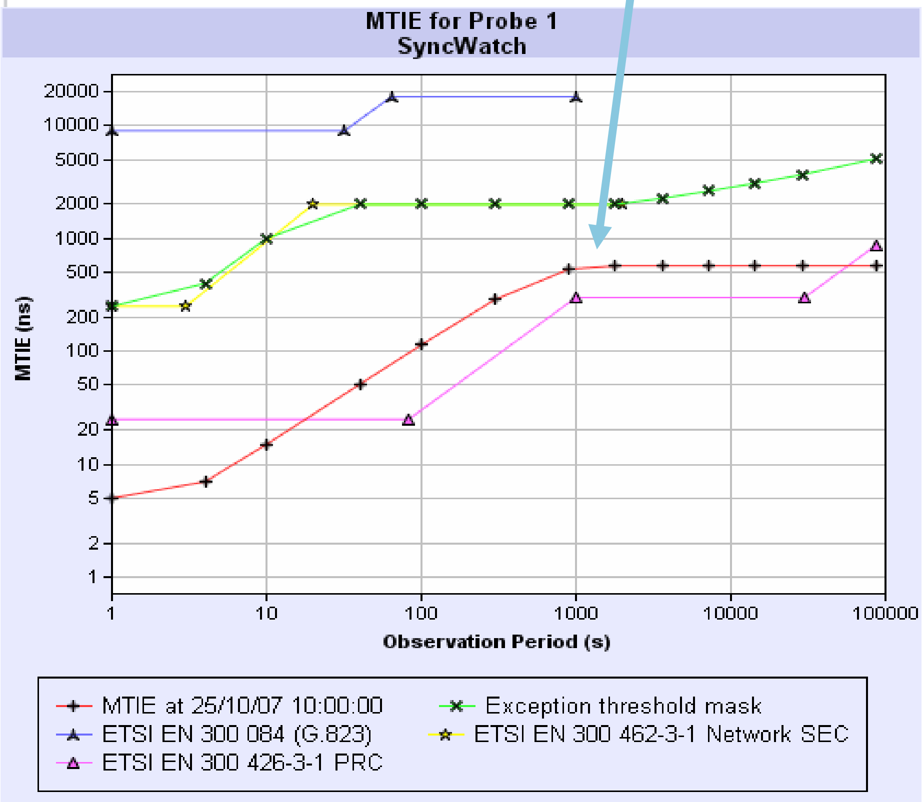
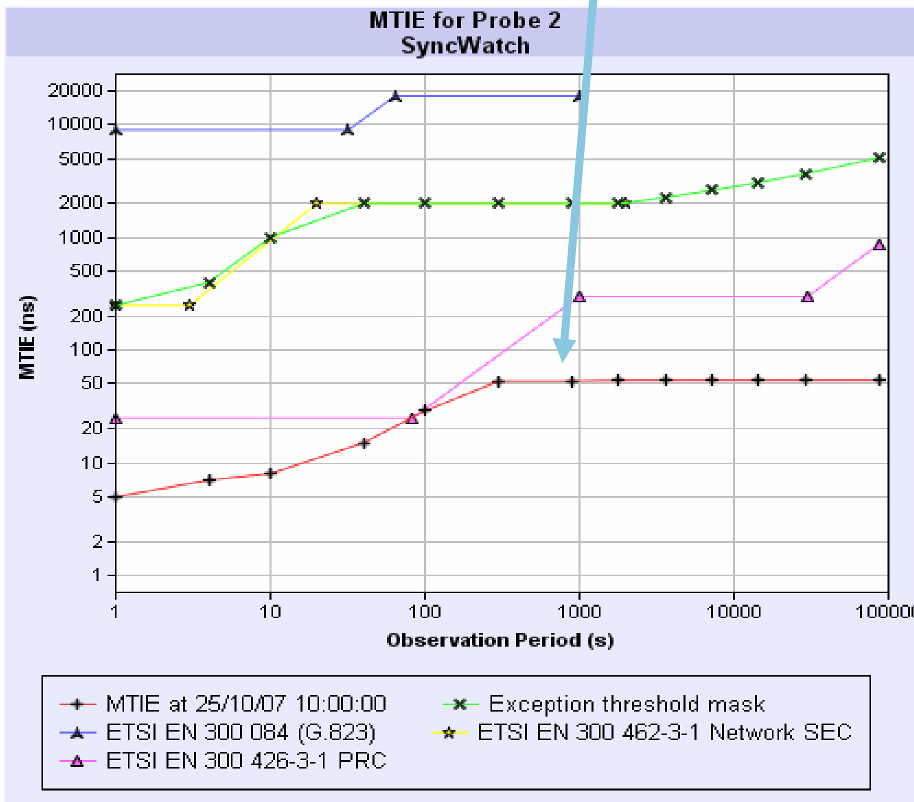
Phase III results stage 1 - 80% constant load

- Probe 1: Frequency accuracy of the recovered 2Mb/s E1 signal by the SHDSL modem compared with the 2.048 MHz SSU (Symmetricom 5540)
- Probe 2: Frequency accuracy of the recovered 2Mb/s E1 signal by the SHDSL modem compared with the IEEE 1588 slave board 2.048 MHz output (Semtech TopSync), measuring the degradation introduced by SHDSL (with NTR support)

Overall accuracy pretty much the same as IEEE 1588v2 slave clock

SHDSL does not introduce any major degradation





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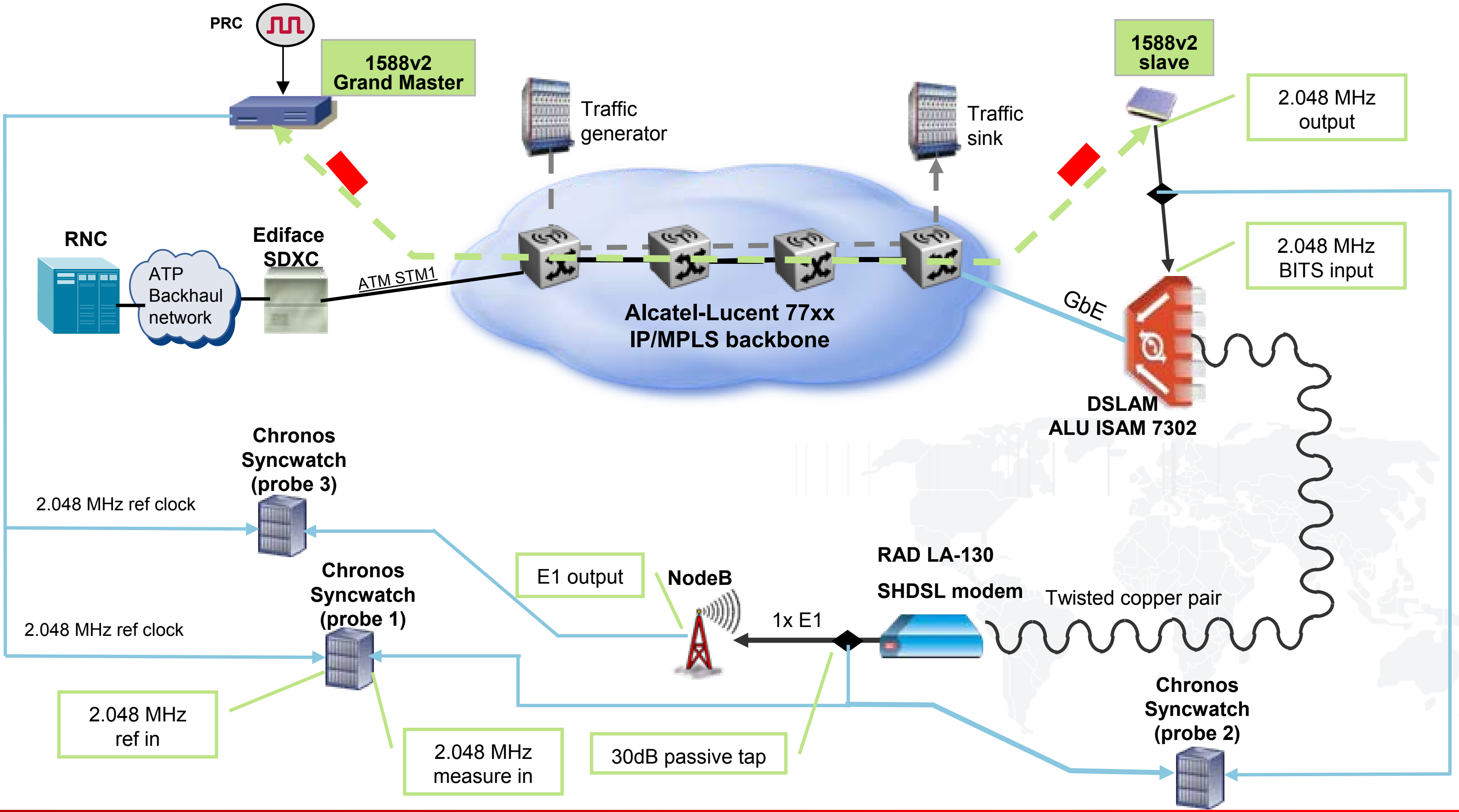
Phase III - IP DSLAM synchronisation with IEEE 1588v2
Stage 2 test setup

Loaded E1 over SHDSL lines with traffic flowing between RNC and NodeB

Probes at input and output of NodeB to understand the effect of NodeB filtering

Tests currently ongoing…



Summary

The activities being carried out by Vodafone Group are helping Vodafone to…

Determine the sync strategy for VF	• Interim solutions will be a combination between adaptive clocking, sync Ethernet and GPS depending on requirements • Long term solution is IEEE 1588v2 in combination with GPS/Loran/… and sync Ethernet
Support 1588v2 vendors refine their solutions to meet VF requirements	• Test IEEE 1588v2 algorithms under very stressed (and hopefully unrealistic) conditions • Test IEEE 1588v2 with different backhaul infrastructures
Determine the 'limits' of IEEE 1588v2 with different scenarios	• How many and where to place IEEE 1588v2 grand masters • Understand for which situations QoS is necessary • Assess whether (and if so, where) boundary clocks are necessary
Assess the maturity level of IEEE 1588v2	• 9-12 months still necessary for algorithm refinements to cope with all possible scenarios • Widespread adoption of IEEE 1588v2 to start in **2009** when network nodes with integrated IEEE 1588v2 chipsets should be available

Next steps

Conclude all the lab tests (up to Phase IV)

Perform live trials on some selected VF OpCos

Start engaging VF strategic base station and multi-service routers vendors to express VF preference for sync solutions

Continue engagement with the relevant parts of Vodafone concerning the roll-out of the preferred solutions at global level

Acknowledgments

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SEMTECH

tellabs®

Symmetricom

Chronos Technology

Alcatel·Lucent

RAD data communications

Horsebridge Network Systems Limited

Nokia Siemens Networks

brilliant

OSCILLOQUARTZ

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