KEYSIGHT

WSTS

802.1AS Time synchronization over WiFi

Alon Regev
March 16, 2023

Agenda

- Brief 5G architecture
- Anatomy of an RU
- O-RAN defined tests
- Test Setup
- Exemplary test results
- Conclusion

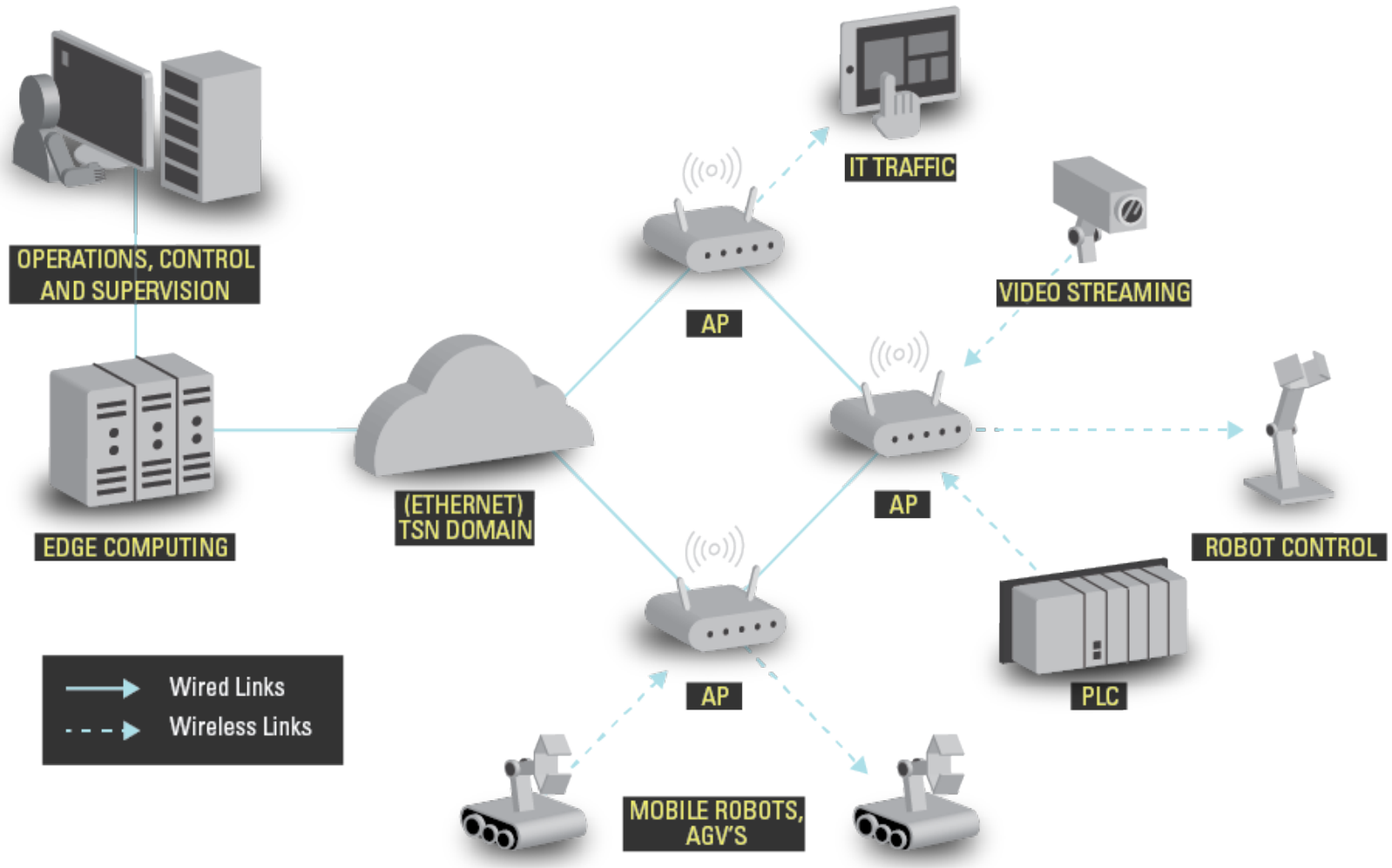
Wireless Time Sensitive Networks: Un-wiring the factory

Increasing demand for automation requires **adaptability and flexibility** of industrial control and communication systems.

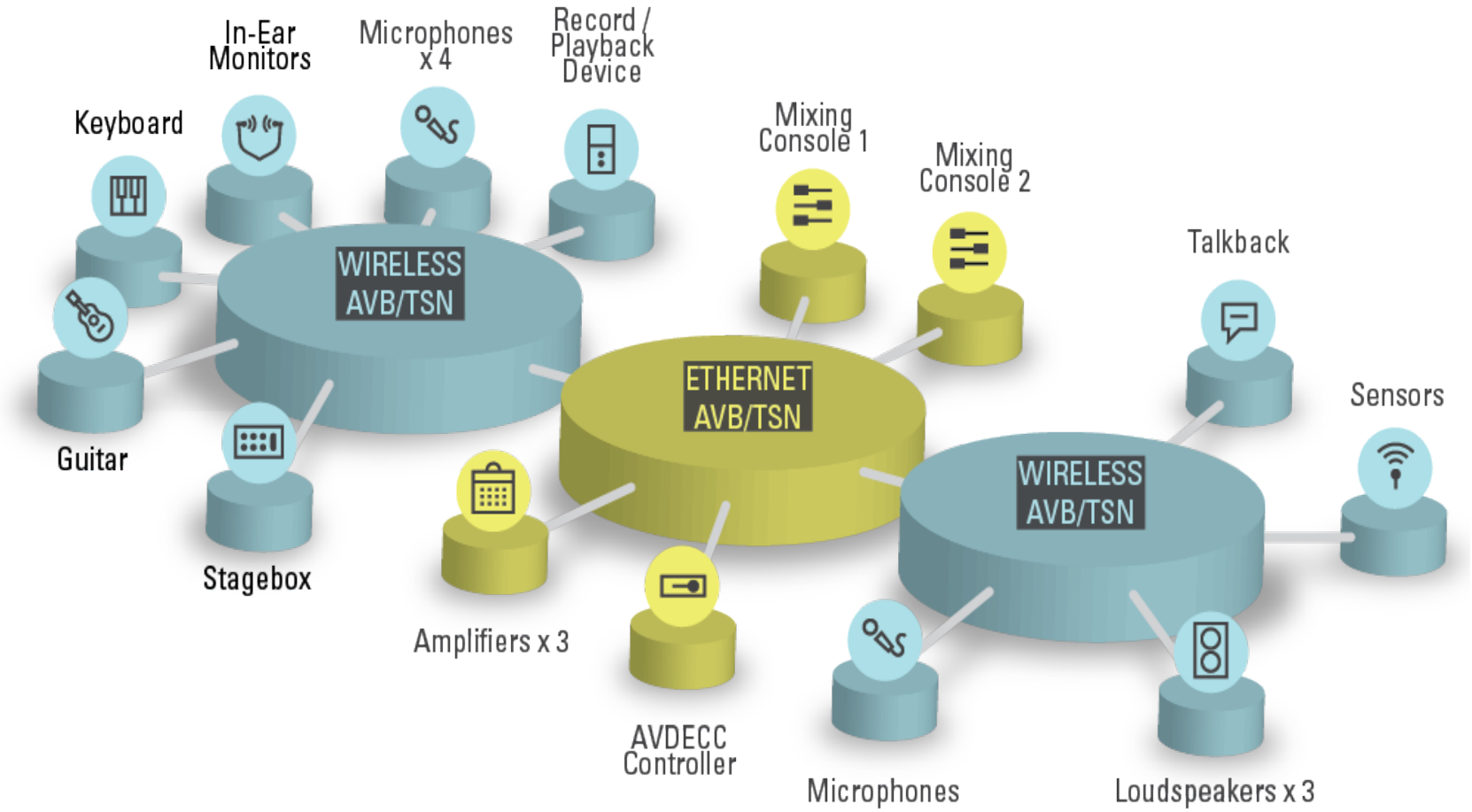
"In a wired system, the **cost of each additional instrument requires extra wiring and the associated labor, equipment, and maintenance**. Wireless can save 20 to 30% in simple configurations. Cost reductions can be even more compelling in scaled installations. "

Source: ISA In-Tech magazine Nov-Dec 2014

Wireless usecase in Industrial



Wireless Pro-AV usecase

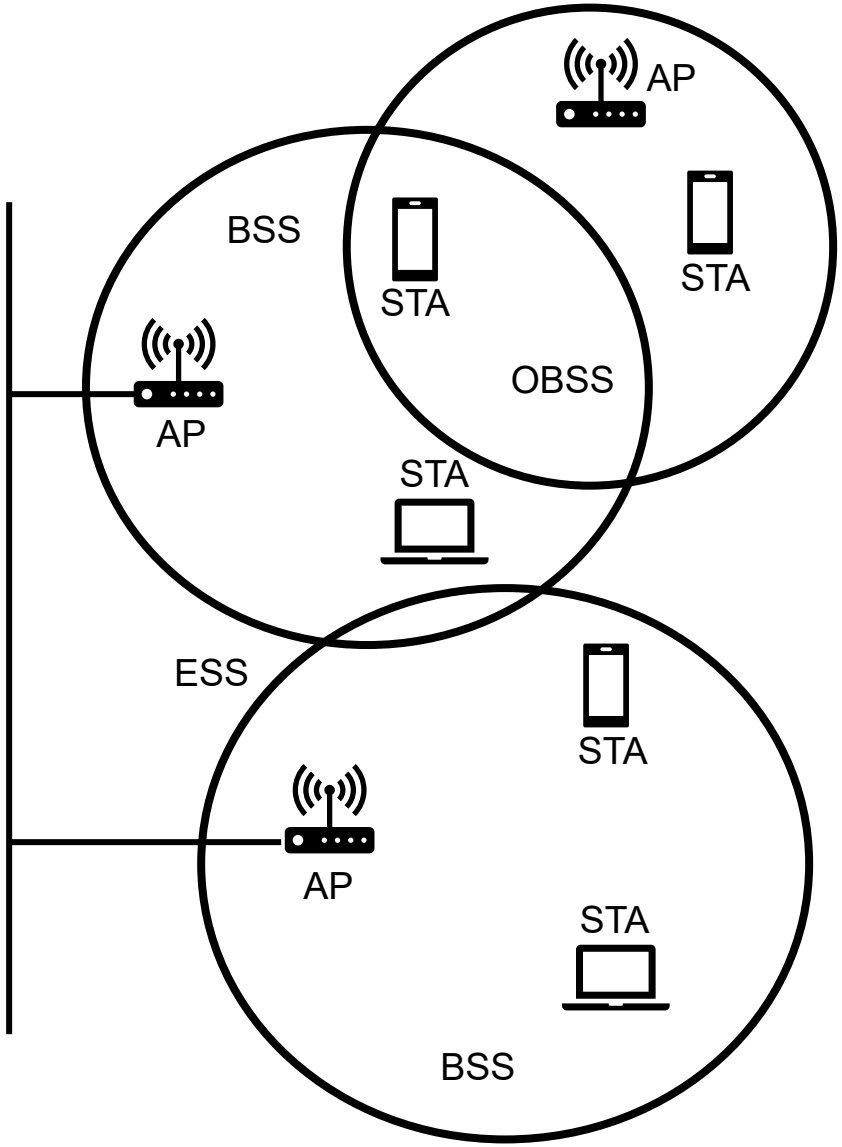


Wireless is different than wired

- Wireless medium has no observable boundaries
- Medium is less reliable
- Medium is shared
- Topologies change dynamically
  - Due to movement
  - Due to changes in signal conditions

802.11 Introduction: Nomenclature

- Station (STA) = A device on the wireless network
- Access Point (AP) = the “gateway” between the wired and wireless network
- Basic Service Set (BSS) = Set of stations associated with one AP
- Basic Service Area (BSA) = area containing members of a BSS
- Overlapping Basic Service Set (OBSS) = A different BSS operating on the same channel as the station’s BSS and within the BSA (partly or wholly).
- Extended Service Set (ESS) = One of more BSSs connected via a network that appear as a single logical entity
- Extended Service Area (ESA) = area containing members of an ESS



Traditional 802.11: Introduction

- Use license-exempt spectrum
  - 2.4, and 5 GHz frequency bands (802.11ax adds 6GHz band)
  - Other 802.11 and non-802.11 devices use the same spectrum
  - Transmit power is limited
- CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance)
  - Stations detect when medium is available
  - Random backoff taken to avoid collisions
- A station can transmit for the length of its TXOP (Tx Opportunity)
- Ack (or BlockAck) confirms reception of the frame
  - Frames are retransmitted if no ack is received
- Various Data Protection mechanisms are used to prevent other stations from interfering with a station's transmit opportunity and transmission

802.11 History

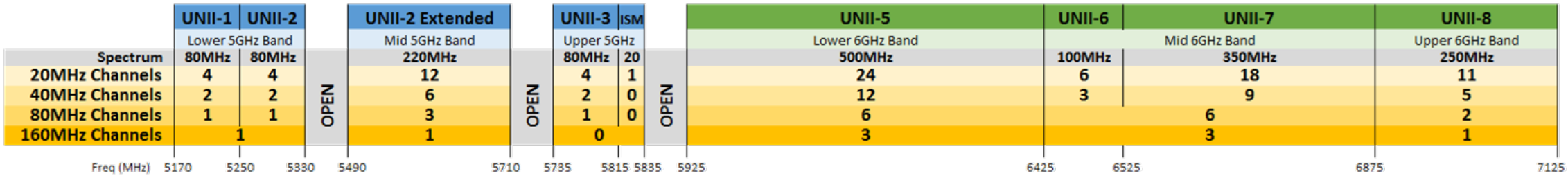
Specification	Release Date	Frequency (GHz)	Bandwidth (MHz)	Data Rate (Mbit/s)	Key features for TSN
802.11-1997	Jun 1997	2.4	22	1, 2	
802.11b	Sep 1999	2.4	22	1, 2, 5.5, 11	
802.11a	Sep 1999	5	5/10/20	Up to 54	
802.11g	Jun 2003	2.4			
802.11n	Oct 2009	2.4/5	20	Up to 288.8	▪ MIMO beamforming
			40	Up to 600	
802.11ac	Dec 2013	5	20	Up to 346.8	▪ MU-MIMO ▪ More spatial streams
			40	Up to 800	
			80	Up to 1733.2	
			160	Up to 3466.8	
802.11ax (WiFi 6)	Est. June 2020	2.4/5/6	20	Up to 1147	▪ 6 GHz band (greenfield) ▪ OFDMA ▪ Uplink MU-MIMO ▪ BSS coloring ▪ Improvements for dense & outdoor scenarios
			40	Up to 2294	
			80	Up to 4803	
			80+80	Up to 10530	
802.11 Tgbe *(WiFi 7)*	Est. 2024	2.4/5/6	TBD – 320 MHz proposed	TBD – goal of ~30Gbps	▪ URLLC support (driven by TSN requirements)

Additional spectrum (6GHz band)

– Wi-Fi has historically been supported in 2 bands:
  - 2.4 GHz with 3 non-overlapping channels (20MHz)
  - 5 GHz with 25 channels (20MHz)

	2.4GHz Band	5GHz Band	6GHz Band
Spectrum	85MHz	480MHz	1200MHz
20MHz Channels	3	25	59
40MHz Channels	1	12	29
80MHz Channels	0	6	14
160MHz Channels	0	2	7

– New spectrum in **6-7 GHz band**
  - New frequency band reduces congestion in 2.4 and 5 GHz bands
  - Improved performance, less interference and opportunity to take advantage of value of Wi-Fi 6
  - Contiguous 6-7GHz band enables up to 1200 MHz of spectrum vs. 480 MHz in 5GHz band

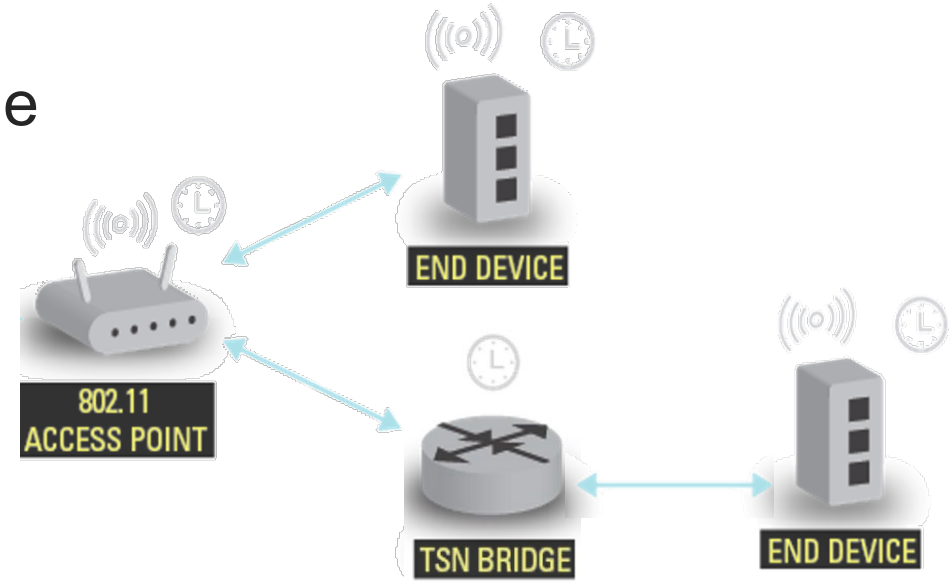


Slide Credit: Dave Cavalcanti, Avnu 5G Study Group

802.1AS (1588 profile) on WiFi

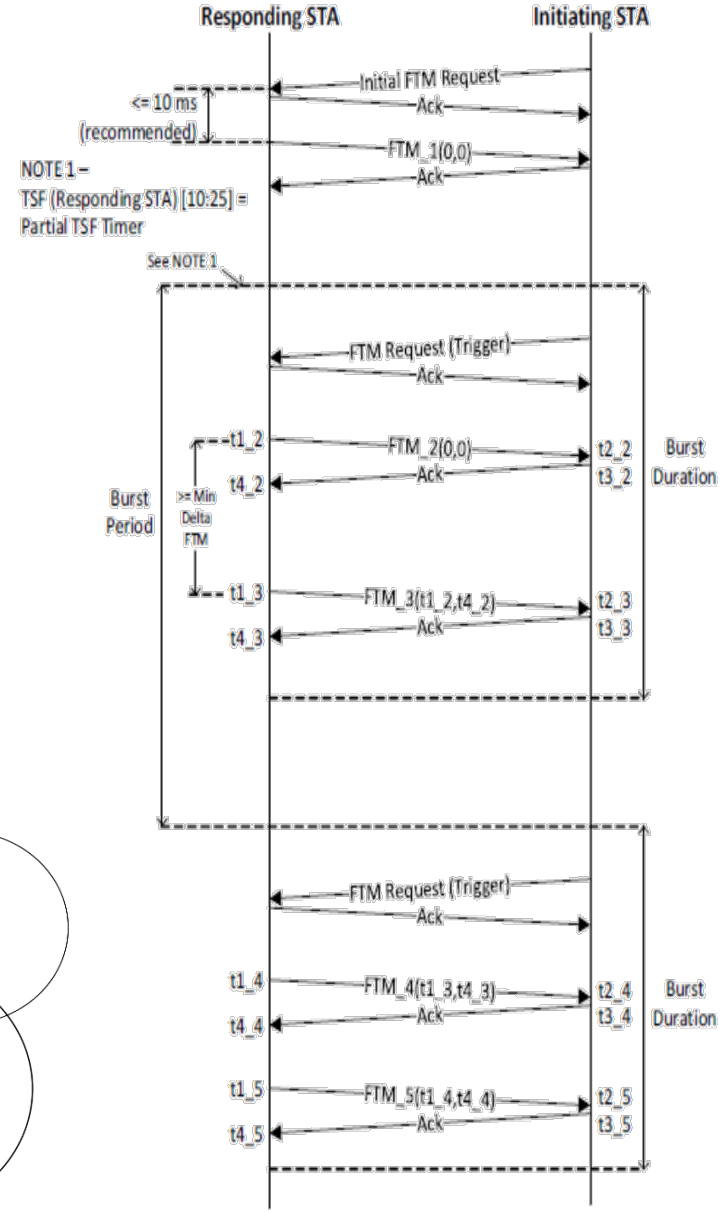
- Access point is an 802.1AS “relay” (1588 TC)
- Non-AP STA may be an end device or relay

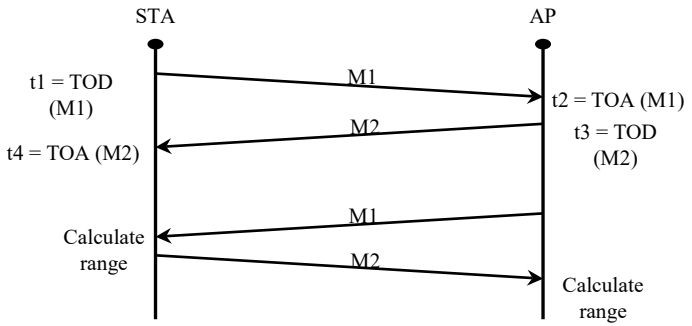
- TM (Time Measurement) or FTM (Fine Time Measurement) feature of 802.11 is used
- Sync, pdelay_request, and pdelay_response replaced by TM or FTM
- Information from Sync/follow_up appended to TM or FTM messages

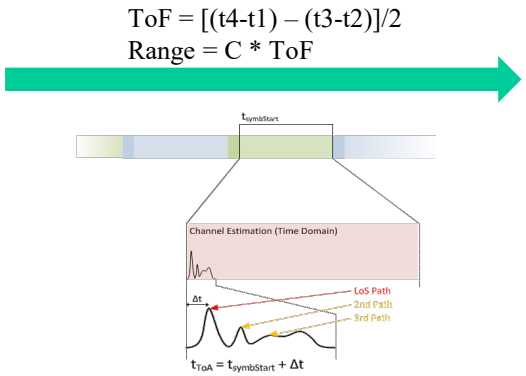


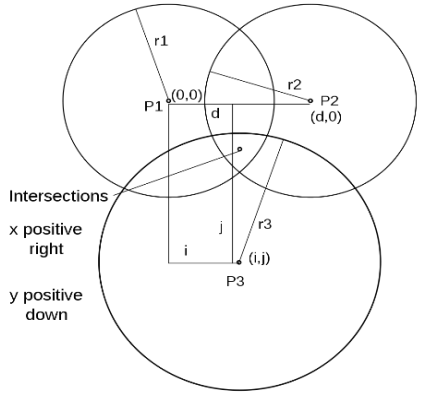
Fine Timing Measurement (FTM)

- A protocol which enables range measurement from an Initiating STA (ISTA) to a Responding STA (RSTA) by measuring Time Of Flight (TOF).
- Predominant usage today: location & navigation services
- FTM initially introduced as fix to the location services and extension of the TM (Timing Measurement) protocol.
- Similar to 1588 pdelay request/response
  - Uses burst of multiple exchanges to get better measurement
  - In each exchange: t1, t4 use responder local counter; t2, t3 use initiator local time
  - t1, t4 from previous FTM exchanges are sent in next exchange





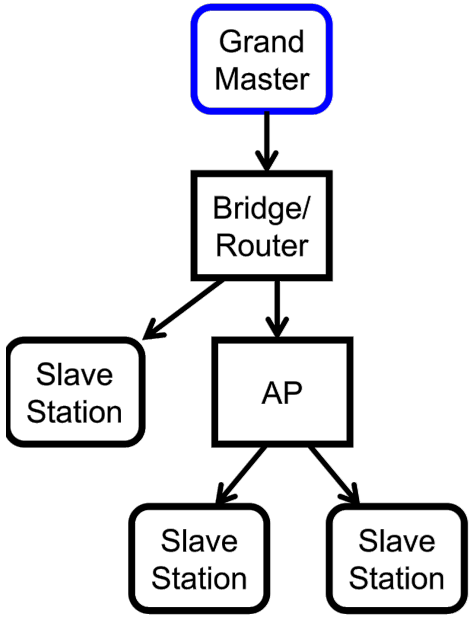


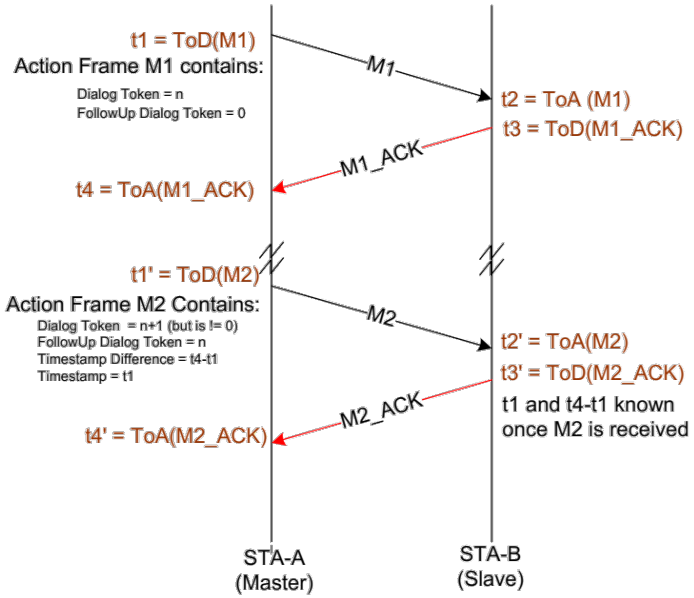


Time Synchronization

- 802.1AS enables the distribution of a single, accurate, time reference across the network (one time reference for the entire TSN domain)
  - 802.11 defined MAC specific support for 802.1AS (e.g. Timing Measurement and Fine Timing Measurement)

802.1AS time synch over 802.11
(defined in the IEEE 802.11-2012 spec)





802.11 Timing Measurement frames are used to compute:

LinkDelay = [(t4-t1)-(t3-t2)]/2

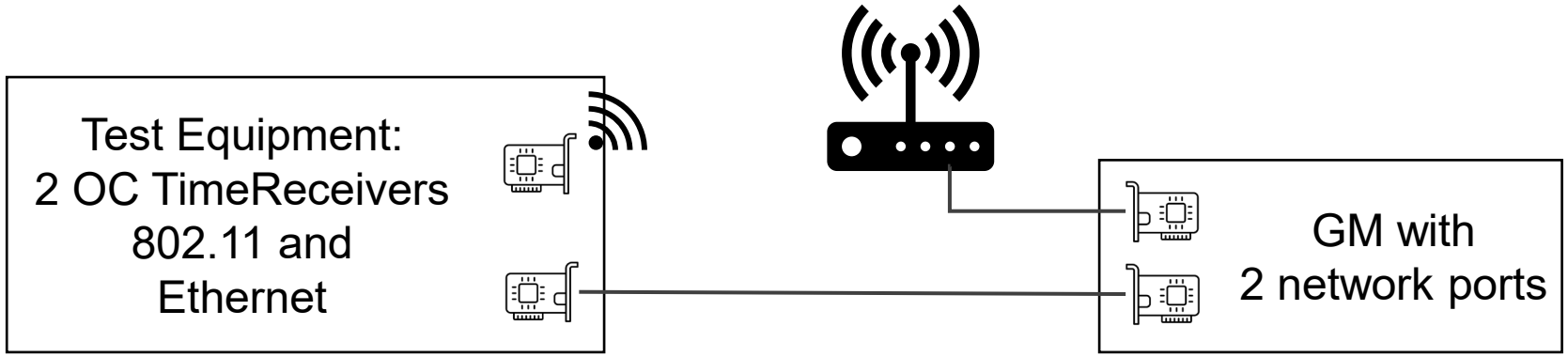
NeighborRateRatio (PPM offset to neighbor) = (t1'-t1)/(t2'-t2)

TimeOffset = [(t2-t1)-(t4-t3)]/2

Slide Credit: Kevin Stanton, Tutorial: The Time-Synchronization Standard from the AVB/TSN suite IEEE Std 802.1AS™-2011
http://www.ieee802.org/1/files/public/docs2014/as-kbstanton-8021AS-tutorial-0714-v01.pdf

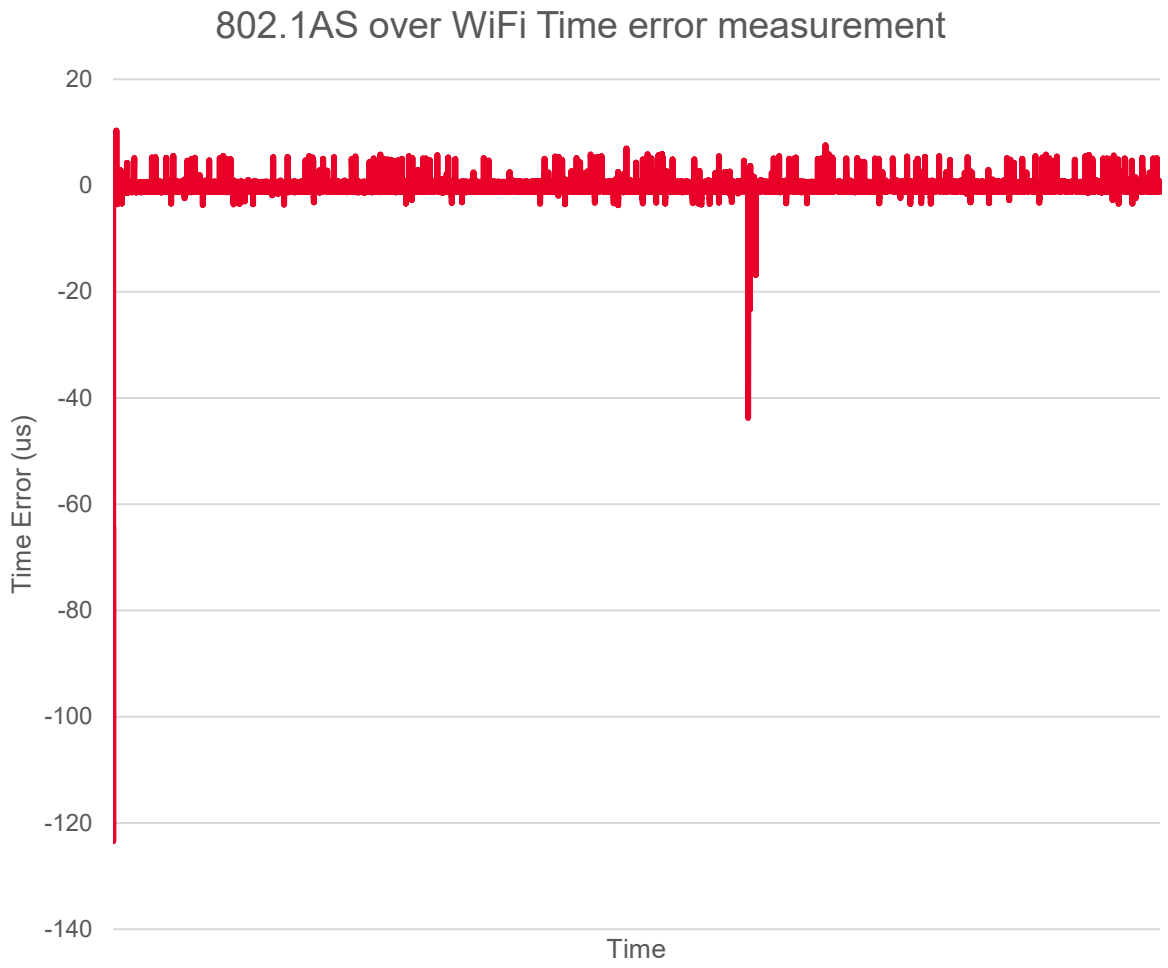
802.11 Time Error test setup

- A GM provides time via 802.1AS both to an 802.1AS capable AP as well as test equipment
- AP acts as an 802.1AS Relay (BC)
- Test equipment contains 2 TireRecieves:
  - 802.11 TimeReceiver receives time from the AP
  - Ethernet TimeReceiver gets time directly from the GM
- Test equipment compares ethernet received time (reference time) to the 802.11 received time (time under test) to measure TE, TIE, MTIE, etc.



802.1AS over WiFi Time Error

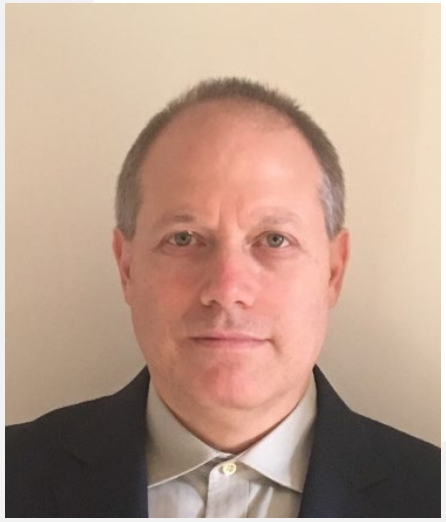
- Test showing prototype results
- AP used does not have HW timestamping on ethernet port limiting performance (and causing spikes)
  - This will be resolved in newer hardware; measurements will be provided
- |TE| is typically < 10µs
  - Addressing AP time sync limitations should get this down to sub-µs levels



KEYSIGHT

WSTS

Questions?



Alon Regev
alon.regev@keysight.com

KEYSIGHT

WSTS

Thank you