The Fundamental Need for Synchronization

ITSF 2014, Budapest

Time to Learn – Tutorial Session

Kishan Shenoi (kshenoi@Qulsar.com)
Qulsar, Inc., San Jose, California

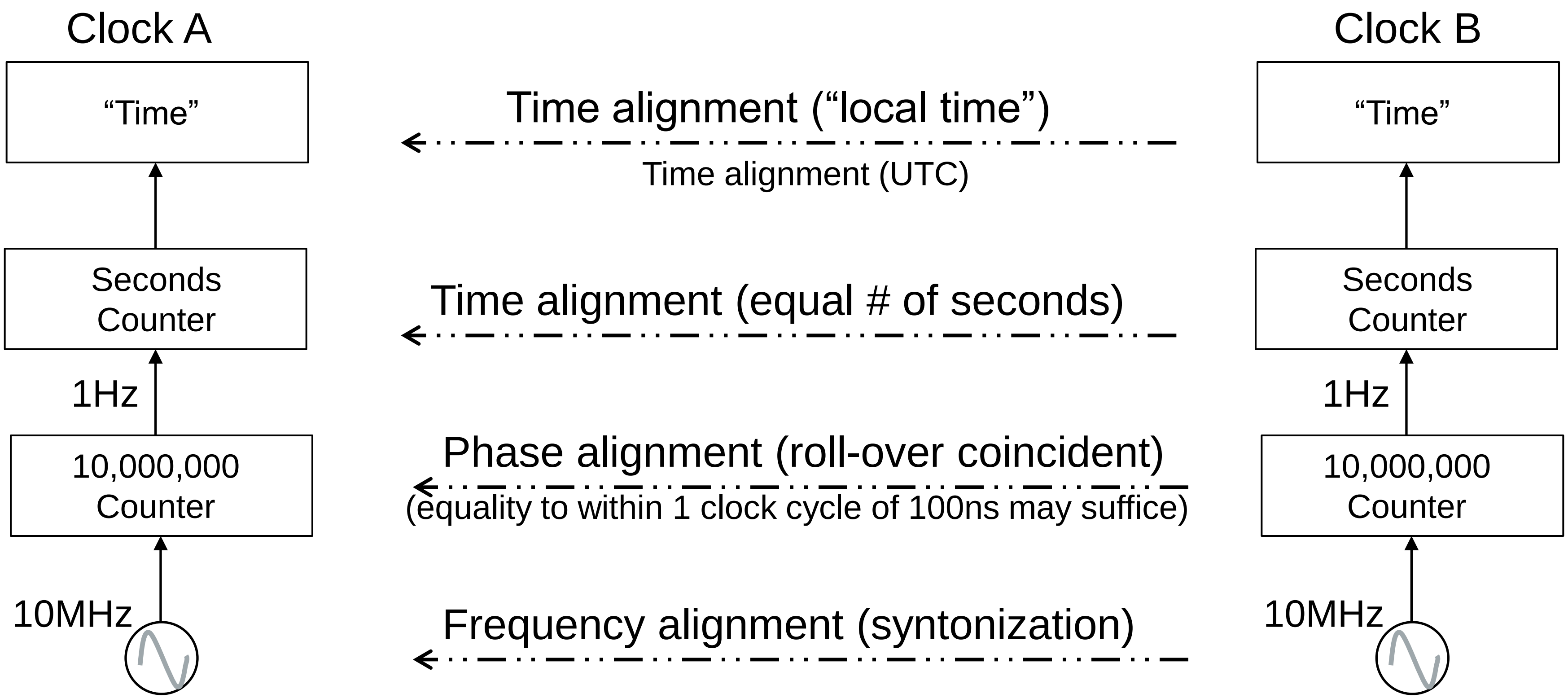
Outline of Presentation

- Notion of Timing Alignment
- Timing Alignment is Fundamental in Telecommunications
  - Digital transmission requires symbol-timing alignment
  - Digital network require synchronization to emulate analog channels
  - Circuit Emulation (CBR over packet) requires timing alignment
  - Wireless (Cellular) requires timing alignment
  - Multimedia requires timing alignment
- Timing in Circuit-Switched (TDM) Networks
  - Synchronous time-division multiplexing
- Timing in Next Generation Networks
  - Impact of packet delay variation (PDV)
  - Principle of timing over packet networks
  - Introduction to packet (PDV) metrics

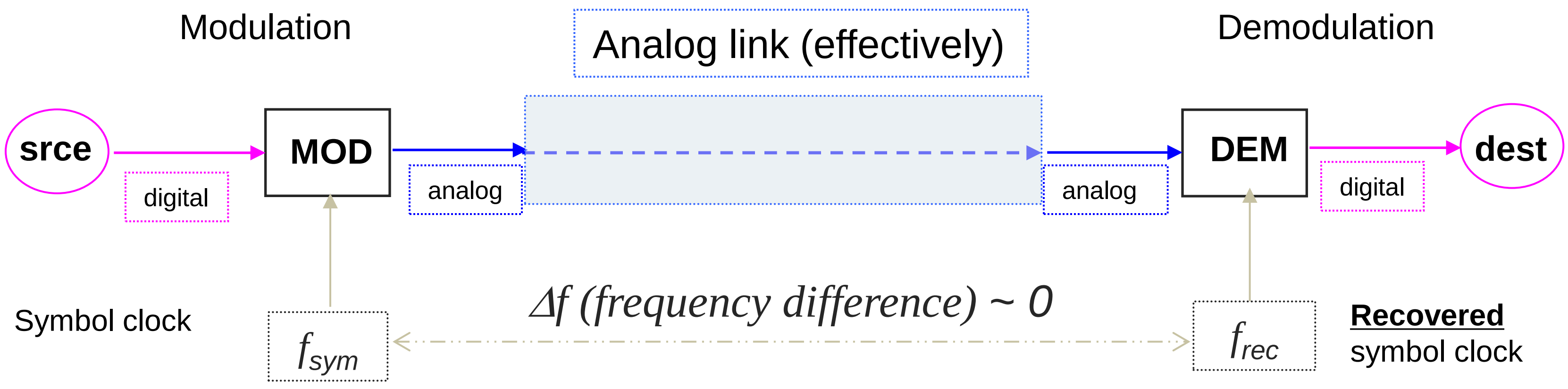
Time and Frequency

QULSAR

- Aligning two time clocks (synchronization) implies:
  - Make frequency B = frequency A (syntonization)
  - Make phase B = phase A (e.g. roll-over instant of 10^7 counter)
  - Make seconds B = seconds A (elapsed time equal; same time origin)
  - Choose same formatting convention (and time-zone, etc.)

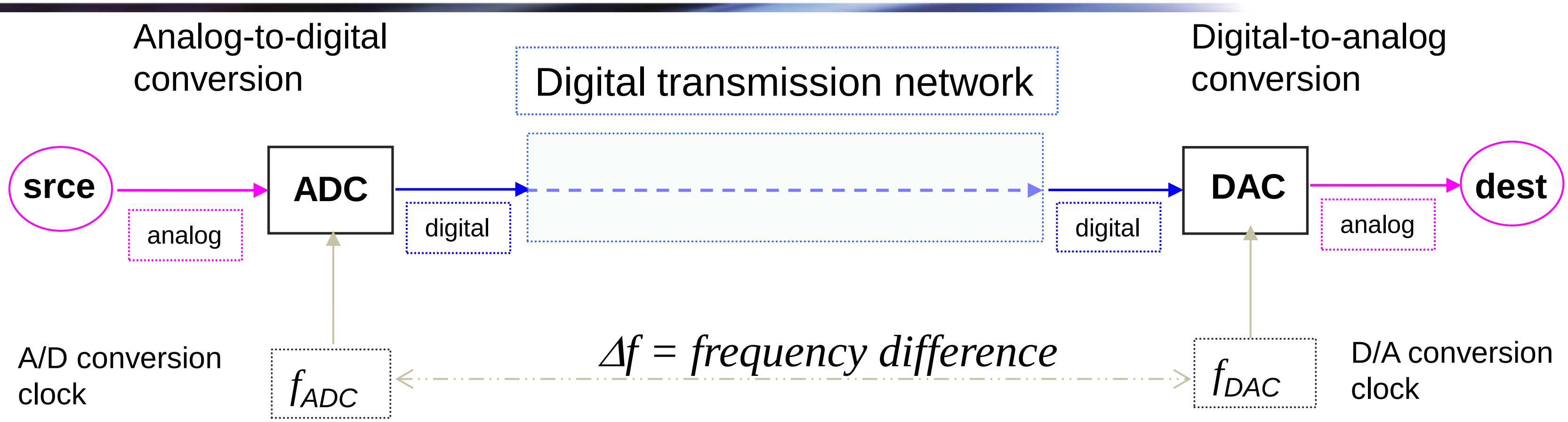


Data transmission schemes require synchronization



- Source/Destination : modulator and demodulator
- Transmitter (modulator) uses a particular symbol clock
  - receiver (demodulator) must extract this clock (Δf ~ 0) for proper data recovery
- The "Analog link" must, *effectively*, mimic an analog wire pair
  - Frequency translation (e.g. DSB-AM) is benign, Doppler (pitch modification effect, PME) is not benign (Δf ~ Doppler)

Timing Alignment required in Voice-Band Transmission



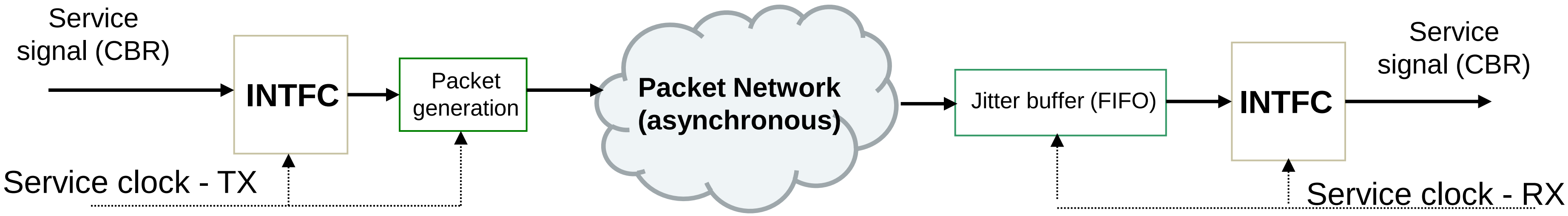
$\Delta f \neq 0$ implies conversion mismatch

Primarily affects voice-band data (Fax, modem) and real-time video

- Source/Destination : Voice/video/fax terminal
- The digital transmission network *emulates* an analog circuit (the original circuit emulation)
- Impact of frequency difference (Δf):
  - Eventually buffers will overflow/underflow (e.g. slips) (“obvious”)
  - Pitch Modification Effect (PME) (analogous to *Doppler*) makes recovered symbol clock ≠ transmit symbol clock (not so “obvious”)
  - Recovered waveform ≠ original waveform (more than just additive noise)

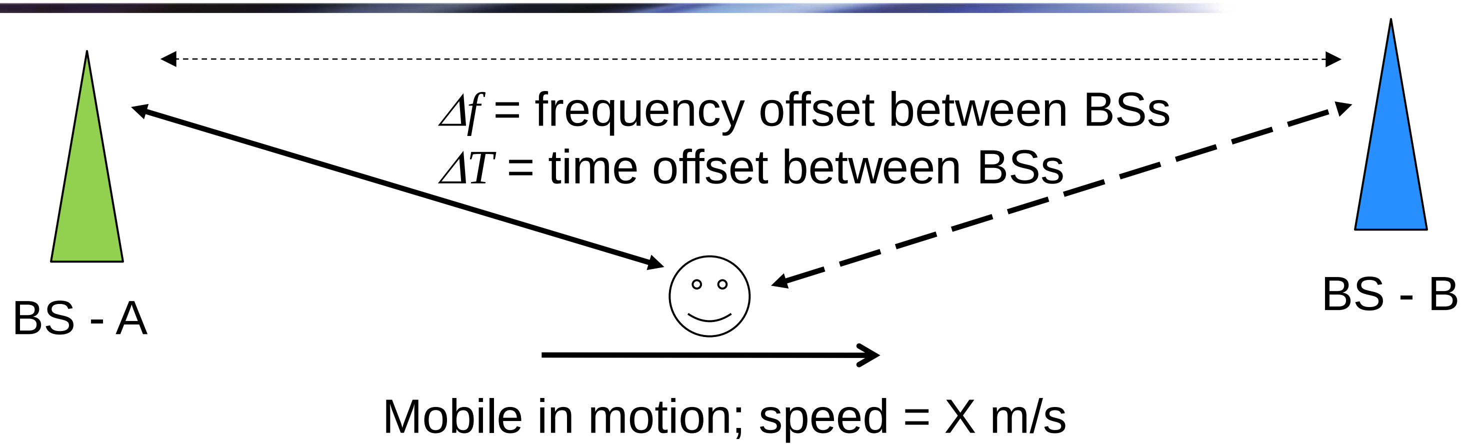
Timing alignment implicit in Circuit Emulation

QULSAR



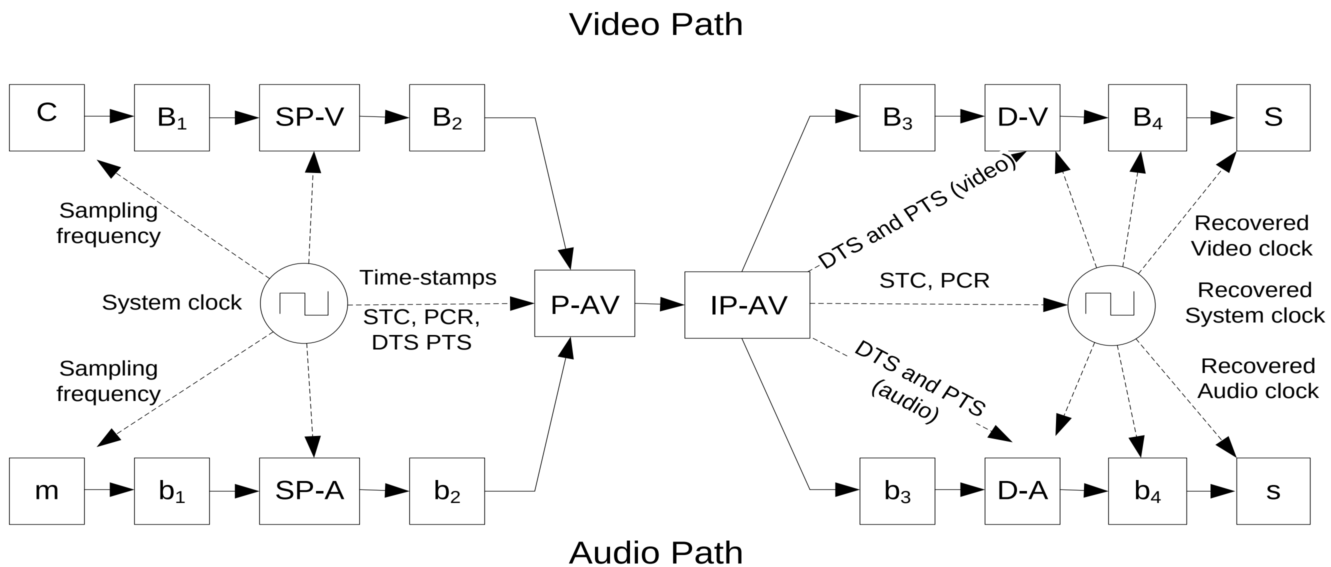
- Network impairments: delay, <u>packet-delay-variation (PDV),</u> discarded packets
- Jitter buffer size: large enough to accommodate greatest (expected) packet-delay-variation. Packet loss concealment is not an option.
- Causes of packet "loss":
  - Network drops packets (bit errors, congestion)
  - Jitter buffer empty/full (excessive packet-delay-variation)
- Key to ***<u>Circuit Emulation</u>*** :
  - Ensure packet loss is (essentially) zero.
  - Make RX and TX service clocks "equal".
  - Note: <u>If RX ≠ TX then jitter buffer is going to overflow/underflow</u>

Timing Alignment in Wireless



- When hand-over occurs, the mobile must reacquire carrier frequency
  - Mobile in motion (X m/s) introduces a Doppler shift (X/c)
  - Loop bandwidth wide enough to handle (Δf + X/c +LO) (LO = local oscillator offset)
  - Loop bandwidth should be small from a noise rejection viewpoint
  - Large Δf compromises the reliability of hand-over
- TDD networks <u>require</u> time/phase alignment between A & B
- LTE-TDD & LTE-Advanced require ΔT to be small (microsec) for providing the more bandwidth intensive features

Timing Alignment in Multimedia

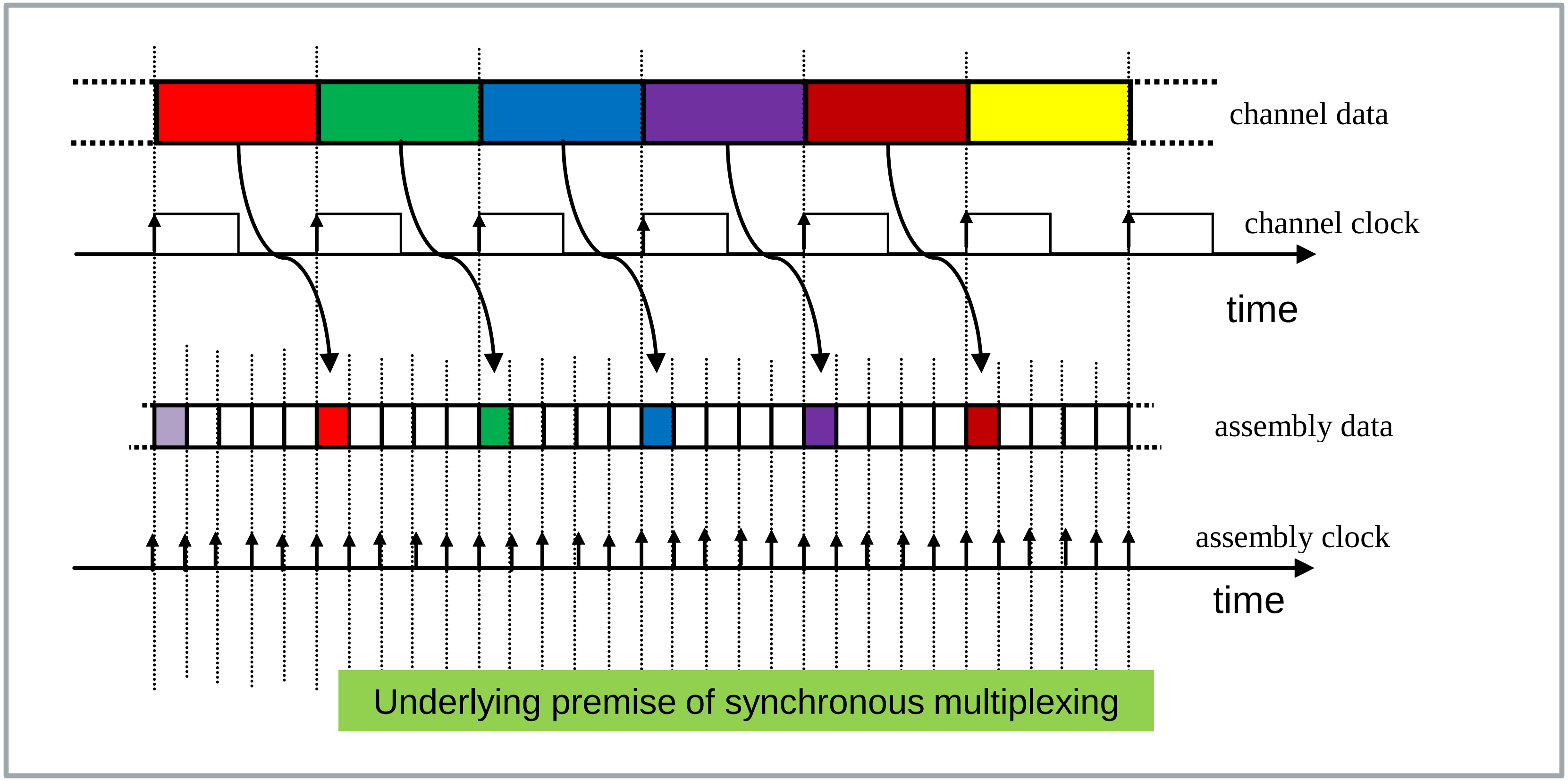


- Frequency offset (wander) between audio and video sampling results in loss of lip-sync
- Frequency offset (wander) between send-side and receive-side system clock results in freeze (video), breaks (audio), and possible loss of lip-sync
- Audio and video streams could come from diverse sources requiring the sources to be synchronized to a common (global) reference

Timing in TDM Networks

- Synchronization is essential for synchronous multiplexing
  - To avoid information loss
- Synchronous multiplexing assemblies are used as carriers of timing information (DS1/E1, SONET/SDH)
  - The recovered line clock is used as a reference for the BITS
  - The transmit signals must meet the “sync” mask for timing information
- Asynchronous multiplexing can preserve timing (up to a point) *if done correctly*
- Bearer signals (DS1/E1) in asynchronously multiplexed assemblies (e.g. DS1 in DS3) can be used as carriers of timing
  - Asynchronous multiplexing is done correctly
- DS1/E1 bearer signals in SONET/SDH are not suitable as carriers of (good) timing
  - SONET/SDH encapsulation of DS1/E1 was done in a way that protects data but not (good) timing information

Synchronous Multiplexing

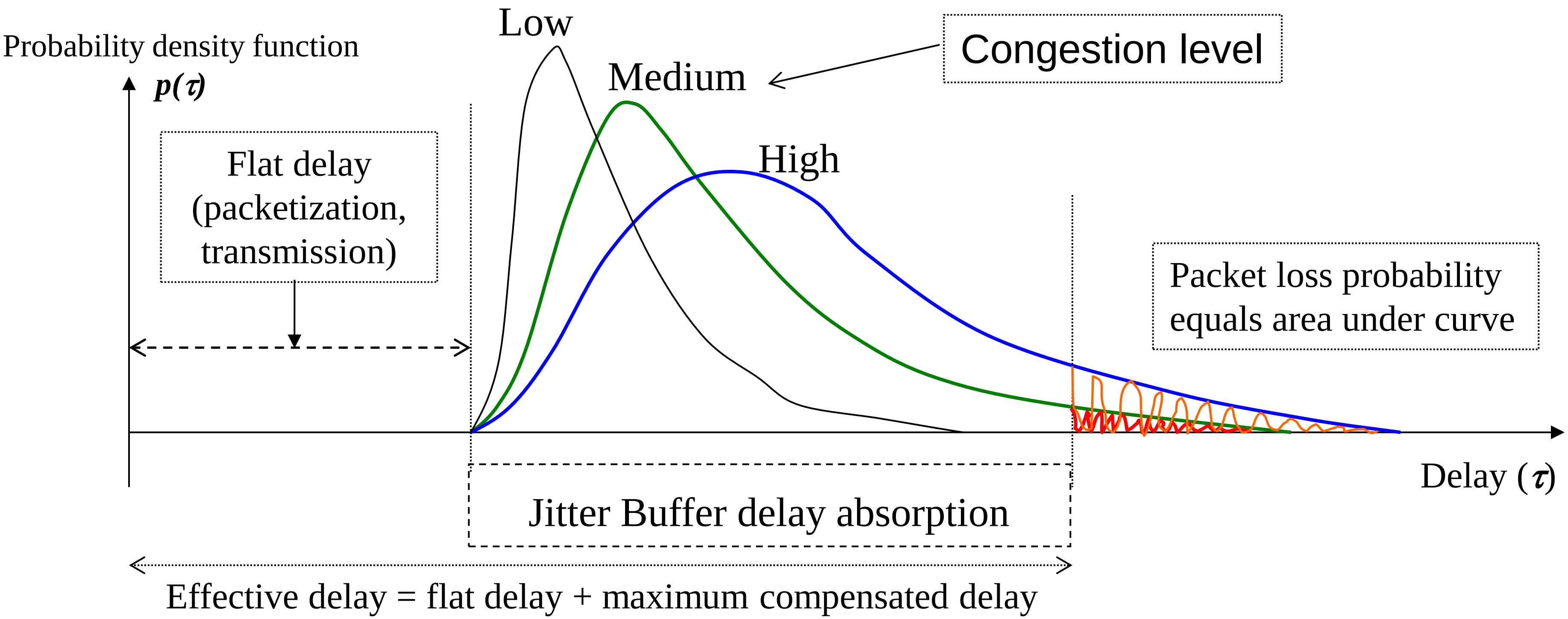


- Predetermined (rigid) ratio between channel clock and assembly clock
- 1-to-1 correspondence between channel bits and allowed bit positions
- *Fractional frequency difference between channel and assembly clocks = 0*

Timing Issues in Next Generation Networks

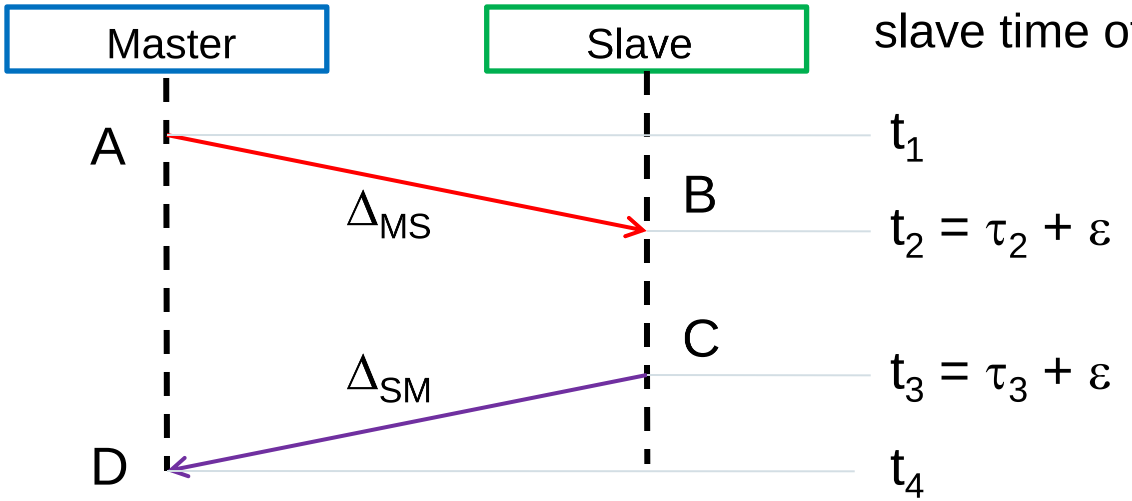
- Next generation networks are based on packet switching as opposed to circuit-switched (i.e. based on TDM)
  - Significant impact of variable delay (packet delay variation)
- Timing requirements remain.
  - Going “IP” does not mean that real-time services no longer need synchronization!
- Transition Phase:
  - Hybrid Networks (IP/TDM islands)
  - Circuit Emulation
- Timing over Packet Networks (packet-based methods)
  - PTP, NTP, adaptive clock recovery
- Monitoring and Testing
  - Metrics for packet-based timing methods (quantifying PDV)

Impact of Packet Delay Variation – VoIP example



- Jitter buffer size: trade-off between latency and packet loss
  - Minimize latency (delay) for voice calls
  - Minimize packet loss for data (voice-band modem) calls
- "Adaptive" jitter buffer techniques adjust buffer size to match PDV
  - Introduce delay for "faster" packets
  - Frequency offset (wander) is a problem

Principles of Packet-based timing methods



$$\varepsilon = \left(\frac{1}{2}\right)\left(t_4 - \tau_3 - \tau_2 + t_1\right)$$

$$\Delta_{MS} = \Delta_{SM} = \left(\frac{1}{2}\right)\left(t_4 - \tau_3 + \tau_2 - t_1\right)$$

- One exchange of packets (M-to-S and S-to-M) provides 4 time-stamps
  - Master knows t_1 and t_4 ; Slave knows τ_2 and τ_3
- t_x is correct time (master) ; τ_x is the slave's idea of time (offset of ε)
- Assumption: transit time from master-to-slave (Δ_{MS}) is equal to the transit time from slave-to-master (Δ_{SM})
- "Errors" arise because the transit time is not the same from packet to packet (packet delay variation) and the path is not reciprocal ($\Delta_{SM} \neq \Delta_{MS}$)

PDV Metrics

- Metrics that quantify PDV and share light on the ability of slave clocks to properly recover timing (phase and/or frequency)
- General background principles:
  - Not every packet has “good” timing information. Excess PDV is best ignored (“packet selection”).
  - For a given path, the floor delay is not load dependent (“lucky packet”) though congestion may make it “unobservable”.
  - Metrics often characterize the “floor behavior”, quantifying:
    - Amplitude distribution (pdf) of the PDV to indicate the number of packets that are near the floor
    - the temporal/spectral characteristics of the PDV associated with these packets

Concluding Remarks

QULSAR

- Timing Alignment is Fundamental in Telecommunications
  - Digital transmission requires symbol-timing alignment
  - Digital network require synchronization to emulate analog channels
  - Circuit Emulation (CBR over packet) requires timing alignment
  - Wireless (Cellular) requires timing alignment
  - Multimedia requires timing alignment
- Timing in Circuit-Switched (TDM) Networks
  - Synchronous time-division multiplexing is based on streams being aligned in frequency
- Timing in Next Generation Networks
  - Packet-based timing transfer can be achieved by using time-stamped packets
  - Packet delay variation (PDV) adversely affects user Quality of Experience and quality of timing alignment in packet-based clocks

Thank You!

Questions?

Kishan Shenoi (kshenoi@Qulsar.com)