Synchronization in Telecom and Mobile Networks

WSTS 2019 Tutorial Session

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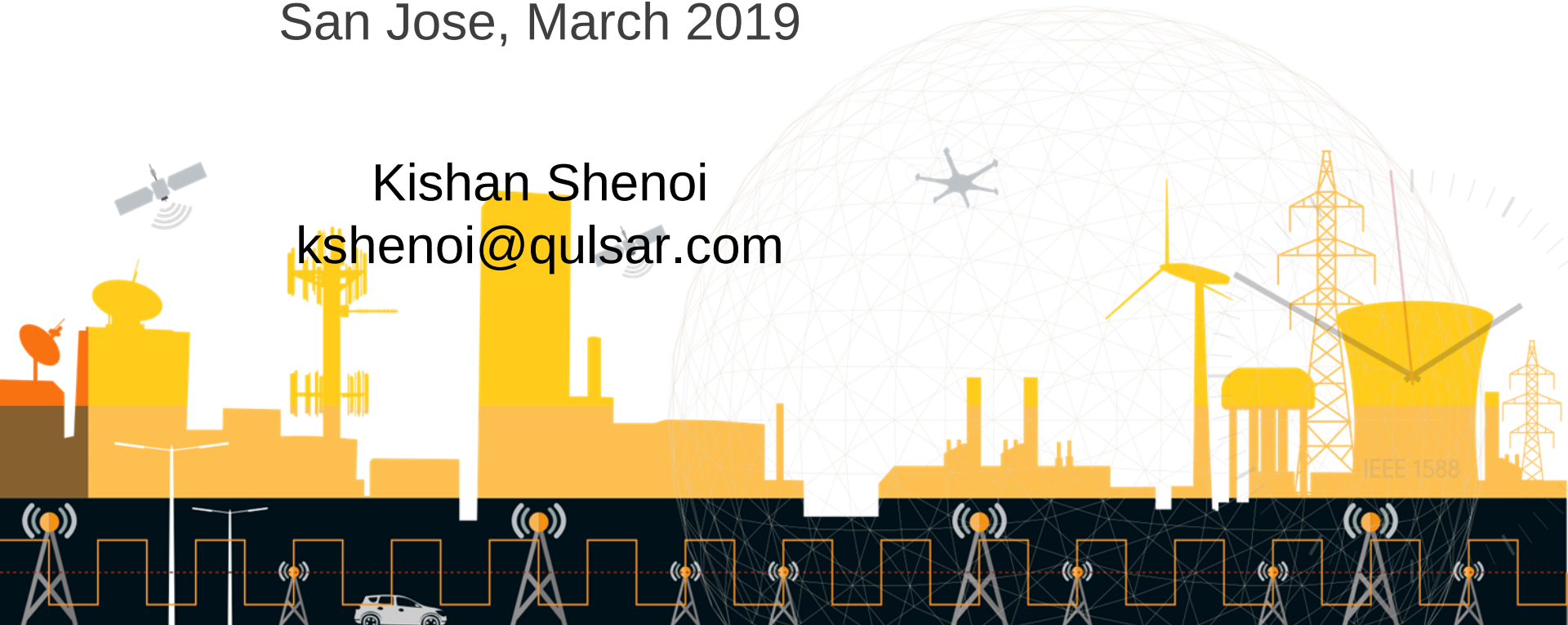
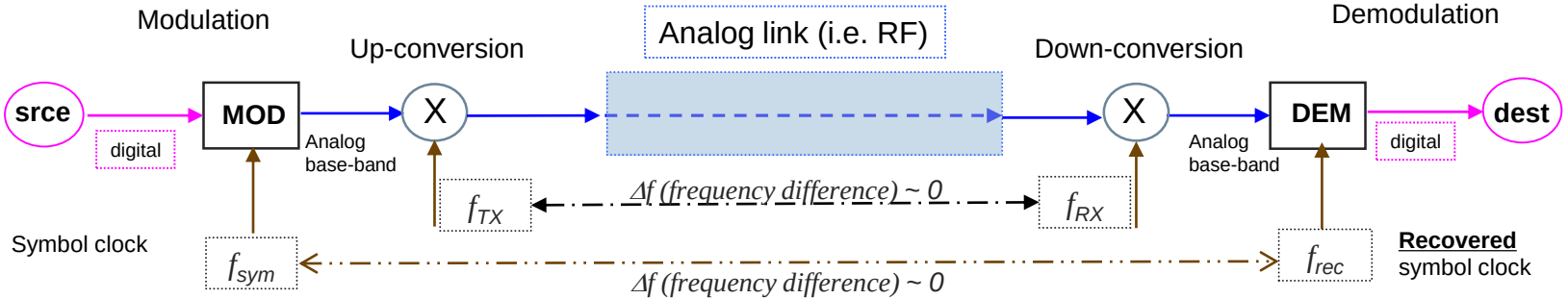


Fundamental need for Synchronization

Timing Alignment is Fundamental in Telecommunications

- Wireless Networks:
  - Digital transmission requires carrier recovery and symbol-timing alignment
  - Wireless (Cellular) requires timing alignment between base-stations
- Circuit-Switched (TDM) Networks:
  - Synchronous time-division multiplexing
  - Digital network require synchronization to emulate analog channels
- Packet-Switched Networks:
  - Circuit Emulation (CBR over packet) requires timing alignment
  - Multimedia requires timing alignment

Wireless transmission schemes require synchronization



- Source/Destination : modulator with up-conversion and demodulator with down-conversion
- Up-conversion from base-band to RF implies a certain carrier frequency
  - Down-conversion requires carrier recovery (need $f_{RX} = f_{TX}$)
- Transmitter (modulator) uses a particular symbol clock
  - receiver (demodulator) must extract this clock ($\Delta f \sim 0$) for proper data recovery

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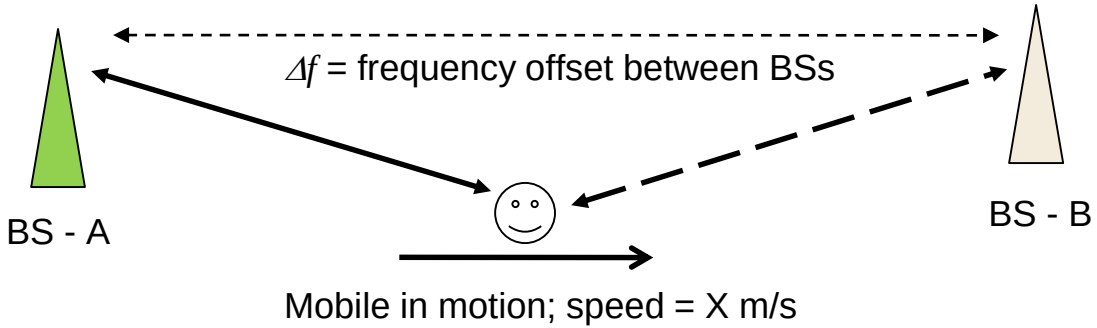
Wireless Synchronization Requirements

- Frequency Accuracy
  - Hand-off considerations
- Phase/Time Accuracy (between base-stations)
  - IS-95 (CDMA) : distinguish between base-stations
  - LTE TDD (Time Division Duplex)
  - New Technologies
    - COMP: Coordinated Multi-Point Processing
    - Carrier Aggregation
    - Geo-location (positioning services)
    - Other Services/Functions (e.g. MBMS, EICIC, etc.)

Timing Alignment in Wireless



- Mobile in motion (X m/s) introduces a Doppler shift (X/c)
  - When hand-over occurs, the mobile must reacquire carrier frequency
  - Large Δf compromises the reliability of hand-over : Δf < 50ppb
- CDMA (IS-95) : base-stations distinguished by time-offset
  - Time Alignment Error (TAE) < 10μs
- Modern Wireless (LTE) requires stringent timing to support special services/functions
  - Time-Division-Duplex (TDD) requires TAE < 3μs

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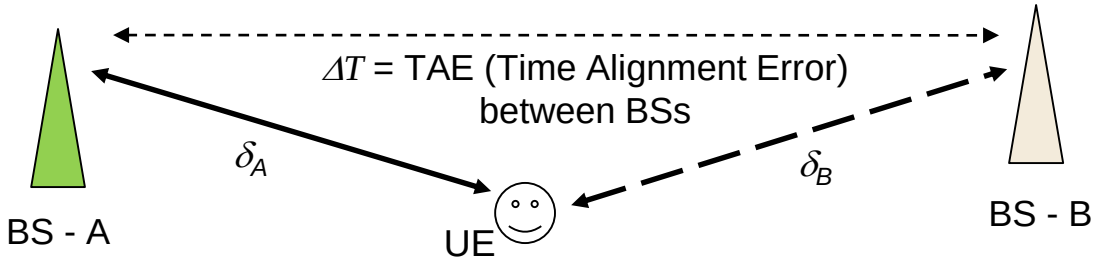
Timing Alignment in Wireless



CoMP can involve more than 2 base-stations

- Coordinated Multi-Point (CoMP):
  - Simultaneous data transmission from multiple sites to single UE (*aka* Joint Transmission, "JT")
  - Joint reception at multiple sites from single UE (*aka* Joint Reception, "JR")
  - Applies to 4G, 5G
- Performance is a function of time alignment error (signal processing requires synchronization)
- According to 3GPP:
  - Typical time offset at UE should be less than 2μs for JT
  - Time offset at UE composed of inter-cell TAE and difference of propagation delays
  - For JT, TAE should be less than 260ns (based on simulation studies)
  - For JR no special requirements have been established

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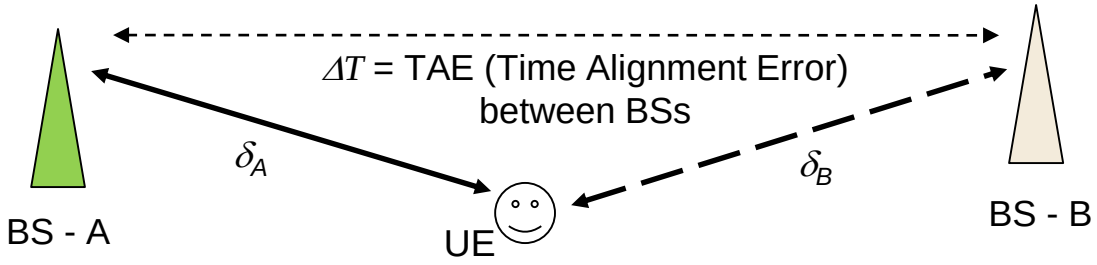
Timing Alignment in Wireless



- Carrier Aggregation (CA):
  - Use of multiple carriers in the same or different frequency bands to increase mobile data throughput
  - Joint reception at UE from single site or multiple sites
  - Multiple cases: (a) same carrier with contiguous time-slots; (b) same carrier with non-contiguous time-slots; (c) different carriers
- Performance is a function of time alignment error (signal processing requires synchronization)
- According to 3GPP:
  - Intra-band contiguous CA : TAE ≤ 130ns
  - Intra-band non-contiguous CA : TAE ≤ 260ns
  - Inter-band CA : TAE ≤ 260ns

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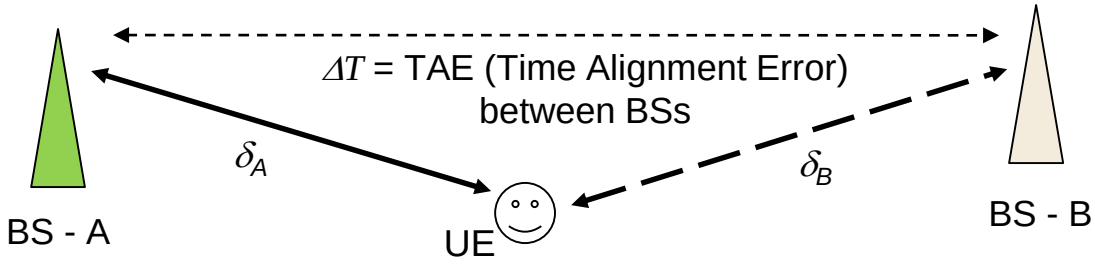
Timing Alignment in Wireless



Positioning must involve 3 or more base-stations

- Geo-Location (Positioning)
  - Joint reception at multiple sites from single UE
    - Time of Arrival (TOA) of UE signal at three or more base-stations used to locate UE via *trilateration*
  - Reception at UE from multiple sites
    - Time Difference of Arrival (TDOA) at UE of signal from four or more base-stations enables UE to “locate” itself
- Performance is a function of time alignment error (signal processing requires synchronization)
- Location error affected by:
  - Geometry of situation contributes to GDOP (Geometric Dilution of Precision)
  - Time error contributes to position error (approximately 30cm per nanosecond)
  - Approximate rule: 10ns TAE contributes ~3m in most cases (determined by GDOP)
  - Multi-path effects have a deleterious impact

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Some Wireless Specifications (3GPP Requirements)

Application/ Technology	Accuracy	Specification
CDMA2000	±3 µs with respect to CDMA System Time, which uses the GPS timescale (which is traceable and synchronous to UTC except for leap second corrections) ±10 µs with respect to CDMA System Time for a period not less than 8 hours (when the external source of CDMA system time is disconnected)	[b-3GPP2 C.S0002] section 1.3 [b-3GPP2 C.S0010] section 4.2.1.1
TD-SCDMA (NodeB TDD mode)	3 µs maximum deviation in frame start times between any pair of cells on the same frequency that have overlapping coverage areas	[b-3GPP TS 25.123] section 7.2
WCDMA-TDD (NodeB TDD mode)	In TDD mode, to support Intercell Synchronization and Handoff, a common timing reference among NodeB is required, and the relative phase difference of the synchronization signals at the input port of any NodeB in the synchronized area shall not exceed 2.5 µs	[b-3GPP TS 25.402] sections 6.1.2 and 6.1.2.1
W-CDMA MBSFN	12.8 µs for MBMS over a single frequency network, where the transmission of NodeB is closely time synchronized to a common reference time	[b-3GPP TS 25.346] sections 7.1A and 7.1B.2.1
LTE MBSFN	Values < ±1 µs with respect to a common time reference (continuous timescale) have been mentioned	Under study
W-CDMA (Home NodeB TDD mode)	Microsecond level accuracy (no hard requirement listed)	[b-3GPP TR 25.866] section 8
WiMAX	1) The downlink frames transmitted by the serving base station and the Neighbour base station shall be synchronized to a level of at least 1/8 cyclic prefix length (which is equal to 1.428 µs). At the base station, the transmitted radio frame shall be time-aligned with the 1PPS timing pulse 2) The base station transmit reference timing shall be time-aligned with the 1PPS pulse with an accuracy of ± 1 µs	[b-IEEE 802.16] Table 6-160, section 8.4.13.4 [b-WMF T23-001] section 4.2.2

Source: G.8271/Table II.1 – Time and phase end-application requirements

Some Wireless Specifications (3GPP Requirements)

Application/ Technology	Accuracy	Specification
LTE-TDD (Wide-Area Base station)	3 µs for small cell (< 3 km radius) 10 µs for large cell (> 3 km radius) maximum absolute deviation in frame start timing between any pair of cells on the same frequency that have overlapping coverage areas	[b-3GPP TS 36.133] section 7.4.2
LTE-TDD (home-area base station)	1) 3 µs for small cell (< 500m radius). For large cell (> 500 m radius), 1.33 + $T_{propagation}$ µs time difference between base stations, where $T_{propagation}$ is the propagation delay between the Home base station and the cell selected as the network listening synchronization source. In terms of the network listening synchronization source selection, the best accurate synchronization source to GNSS should be selected. If the Home base station obtains synchronization without using network listening, the small cell requirement applies. 2) The requirement is 3.475 µs but in many scenarios a 3 µs sync requirement can be adopted.	[b-3GPP TS 36.133] section 7.4.2 [b-3GPP TR 36.922] section 6.4.1.2
LTE-TDD to CDMA 1xRTT and HRPD handovers	eNodeB shall be synchronized to GPS time. With external source of CDMA system time disconnected, the eNodeB shall maintain the timing accuracy within ±10 µs with respect to CDMA system time for a period of not less than 8 hours	[b- 3GPP TS 36.133] section 7.5.2.1
LTE-A	Phase/Time requirements for the applications listed below are currently under study: • Carrier aggregation • Coordinated multipoint transmission (also known as Network-MIMO) • Relaying function	[b- 3GPP TS 36.814]

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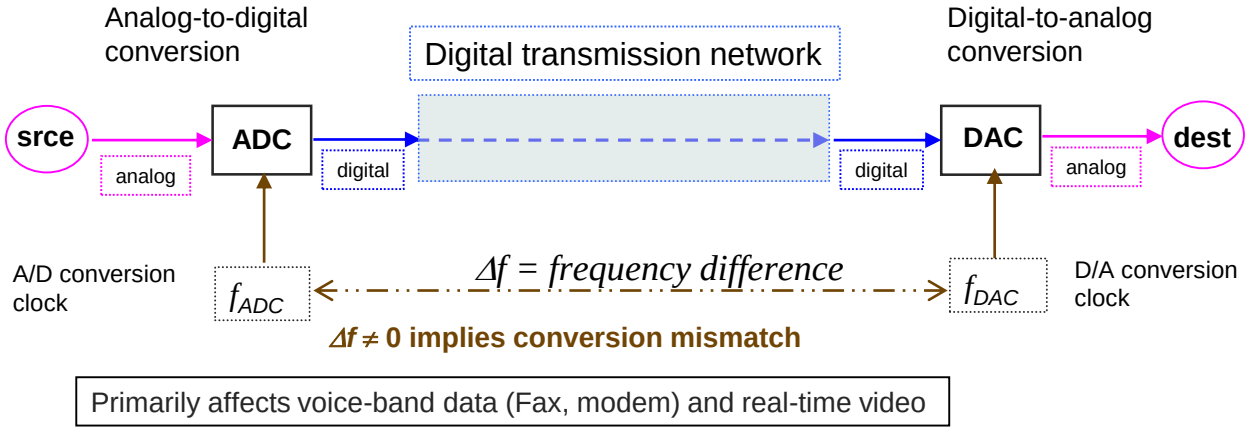
Timing in TDM Networks

- 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 clock is used as a reference for the BITS
  - The transmit signals must meet the “sync” mask for timing information
- Some Thumb Rules in TDM Networks:
  - 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
  - DS1/E1 bearer signals in SONET/SDH are not suitable as carriers of (good) timing because SONET/SDH encapsulation of DS1/E1 was done in a way that protects data but not (good) timing information

Timing Alignment required in Voice-Band Transmission



- 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)

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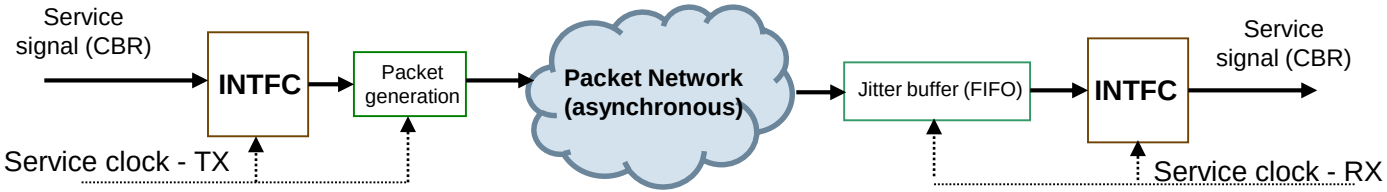
Timing alignment implicit in Circuit Emulation



- Network impairments: delay, packet-delay-variation (PDV), 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 ***Circuit Emulation*** :
  - Ensure packet loss is (essentially) zero.
  - Make RX and TX service clocks "equal".
  - Note: If RX ≠ TX then jitter buffer is going to overflow/underflow

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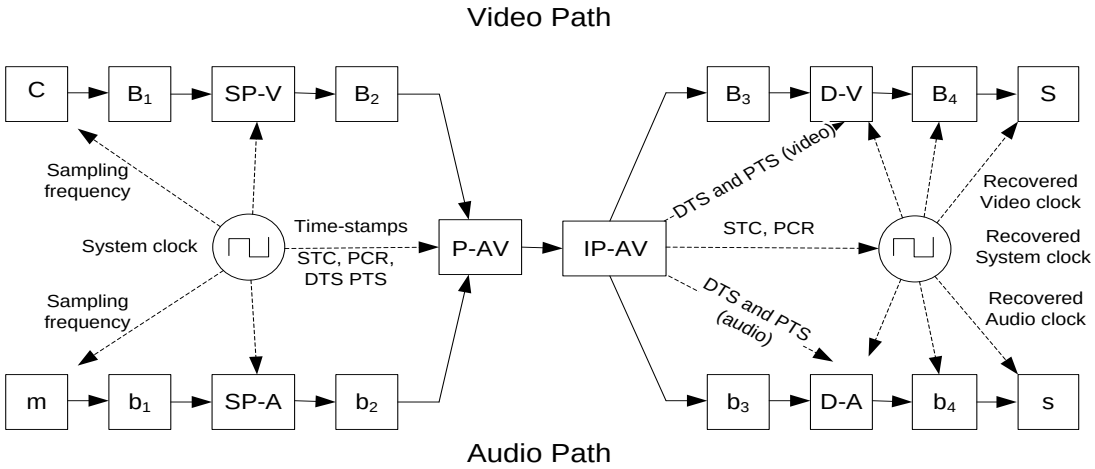
Timing Alignment in Multimedia



- 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

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Stratum Levels - Telecom

- Stratum level represents the intrinsic accuracy of a clock
  - Stratum-1: $1x10^{-11}$ (one part in 10^{11})
  - Stratum-2: $1.6x10^{-8}$ (16 parts per billion, ppb)
  - Stratum-3: $4.6x10^{-6}$ (4.6 parts per million, ppm)
  - Stratum-4: $32x10^{-6}$ (32 parts per million, ppm)
- Implication:

  output frequency is <u>always</u> accurate to *xxx* even if the reference fails and the clock goes into an autonomous mode of operation
- Normal operation:

  output frequency is as accurate as the reference frequency (locked condition) – maintain a hierarchy in any chain of clocks (why?)
- Time-constant achievable:

  ST2 of the order of 10^5 sec (bandwidth ~mHz)
  ST3E of the order of 10^3 sec (bandwidth ~mHz)
  ST3 of the order of 10 sec (bandwidth ~Hz)
  ST4 of the order of 1 sec (bandwidth ~10Hz)

Order of magnitude!

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Thank you …

Questions?

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