FUNDAMENTALS OF SYNCHRONIZATION

Fundamentals of Synchronization

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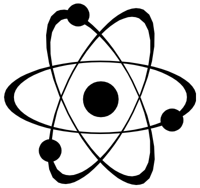
- Time and Frequency
  - Clocks and Oscillators
  - Alignment (frequency, phase, time)
- Fundamental need for Synchronization
  - Data-transmission schemes require synchronization
  - Timing alignment required in voice-band transmission
  - Timing alignment implicit in circuit emulation
  - Timing alignment in wireless
  - Timing alignment in multimedia

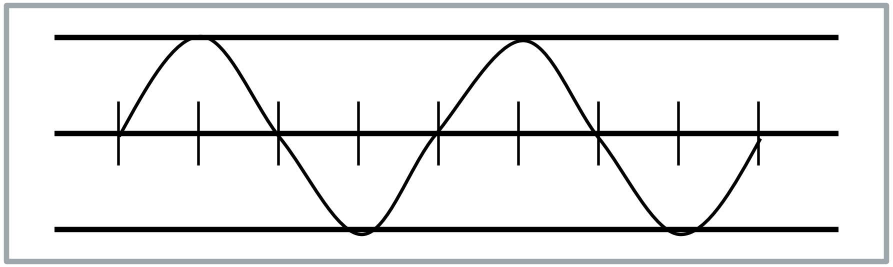
Time and Frequency Sources

- A clock is a frequency device based on physics



Provides "ticks" at precise intervals

- Electronic systems count "ticks" for time interval



"Time-Clock" provides the time elapsed since the "start"

- Time is steered to UTC
  - Defines the "start" plus corrections for astronomy

Time and Frequency

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- Time is an artificial construct.
  - Choose an origin ("epoch") that people can agree on
  - Count the number of seconds (milliseconds /microseconds /etc.) from the origin.
    - Define suitable units such as seconds and minutes and hours and days and so on to express the count from the origin
- Time Interval (e.g. 1 second) is based on a physical property of the Cesium atom.

Timescale	Epoch	Relationship	Leap Seconds	Other
TAI	Jan 1, 1958	Based on SI second	No	Continuous
UTC	Jan 1, 1972	TAI-UTC = 33sec	Yes	Discontinuous
UT-1	Jan 1, 1958	Earth's rotation	No	Astronomical
GPS	Jan 6, 1980	TAI – GPS = 19sec	No	Continuous
Loran -C	Jan 1, 1958	UTC + 23 sec	No	Discontinuous
Local	Jan 1, 1972	TAI-UTC = 33sec	Yes	Discontinuous, Based on Time zone offset
PTP	Jan 1, 1970	TAI – PTP = 10sec	No	Continuous
NTP	Jan 1, 1900	UTC	Yes	Discontinuous

"discontinuous" timescale allows for jumps related to leap seconds

Time and Frequency

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Time and Frequency Need Signals!

- Signals are Physical
  - Accuracy and stability are no better than the physical layer
  - Data layers disrupt the T & F signals
  - Interference to the physical signal blocks access to T & F
- Communications systems are layered with devices only connected to the neighboring layers
  - Sync gets worse farther from the physical layer
- Time accuracy requires access to UTC through a national lab – GNSS used
- GNSS signals are vulnerable!
- Frequency Accuracy requires access to the Cs. Atomic transition

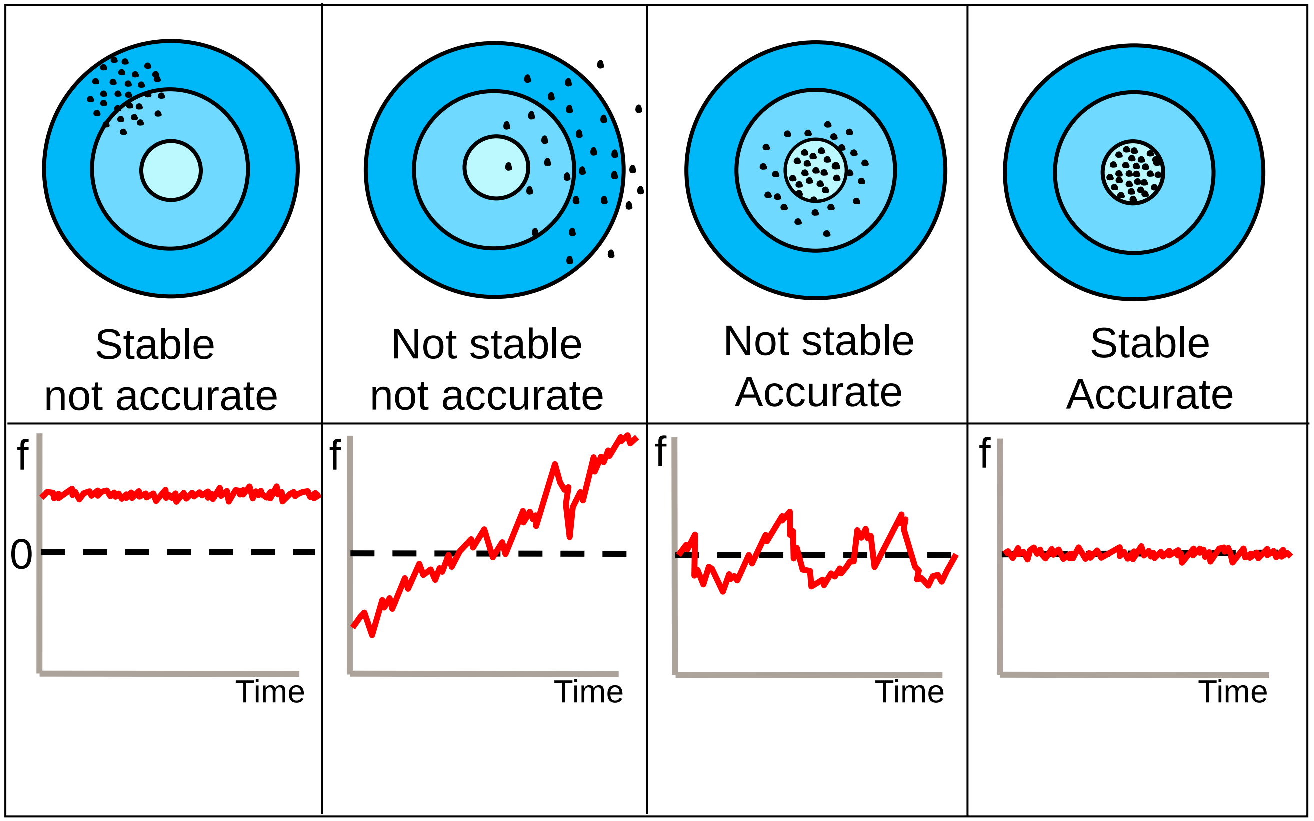
Two Issues Here

- Since a clock is a frequency device, the best clock exhibits only white noise on frequency, hence a random walk in phase. Even the best clocks will walk off unboundedly in time.

- Since the time standard is artificial, time MUST be transferred from the relevant time standard
  - There is often confusion with the human experience of time vs. metrological time. Standard time is a signal plus data
  - Often what is needed is synchronization among locations, not UTC per se, though that is often the most efficient way to achieve synchronization

Accuracy and Stability

- **Accuracy**: Maximum (freq., phase or time) error over the entire life of the clock
- **Stability**: (Freq., phase or time) change over a given observation time interval
- Stability is expressed with some statistical dispersion metric as a function of observation interval (e.g. ADEV, TDEV, MTIE, a.o.)

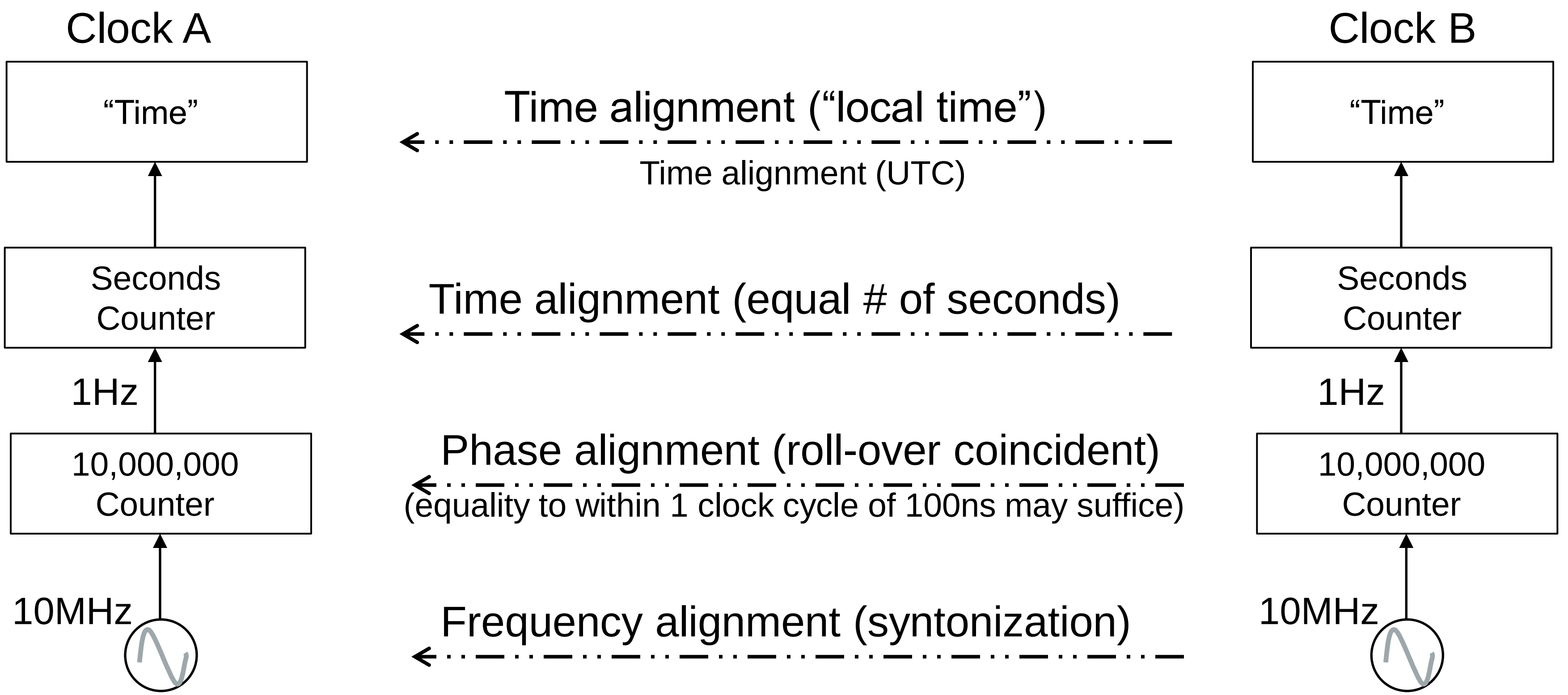


Clocks and Oscillators

- Distinction is more in terms of emphasis
  - Both entities relate to time/frequency
  - Both entities have the notion of periodicity (time-base)
  - Both entities provide "edges", but –
    - Clocks usually associated with edges (square waves) (digital)
    - Oscillators usually associated with waveforms (sine waves) (analog)
- Clock: Device/system that provides timing signals to other devices/systems
  - Emphasis is on time (time interval) accuracy
  - There is the notion of calibration (traceability to UTC)
  - A clock is a "disciplined" oscillator
- Oscillator: Component providing periodic signals
  - Emphasis is on frequency stability (temperature, aging)
  - Waveform integrity is important ("phase noise")
  - Oscillators are components of clocks

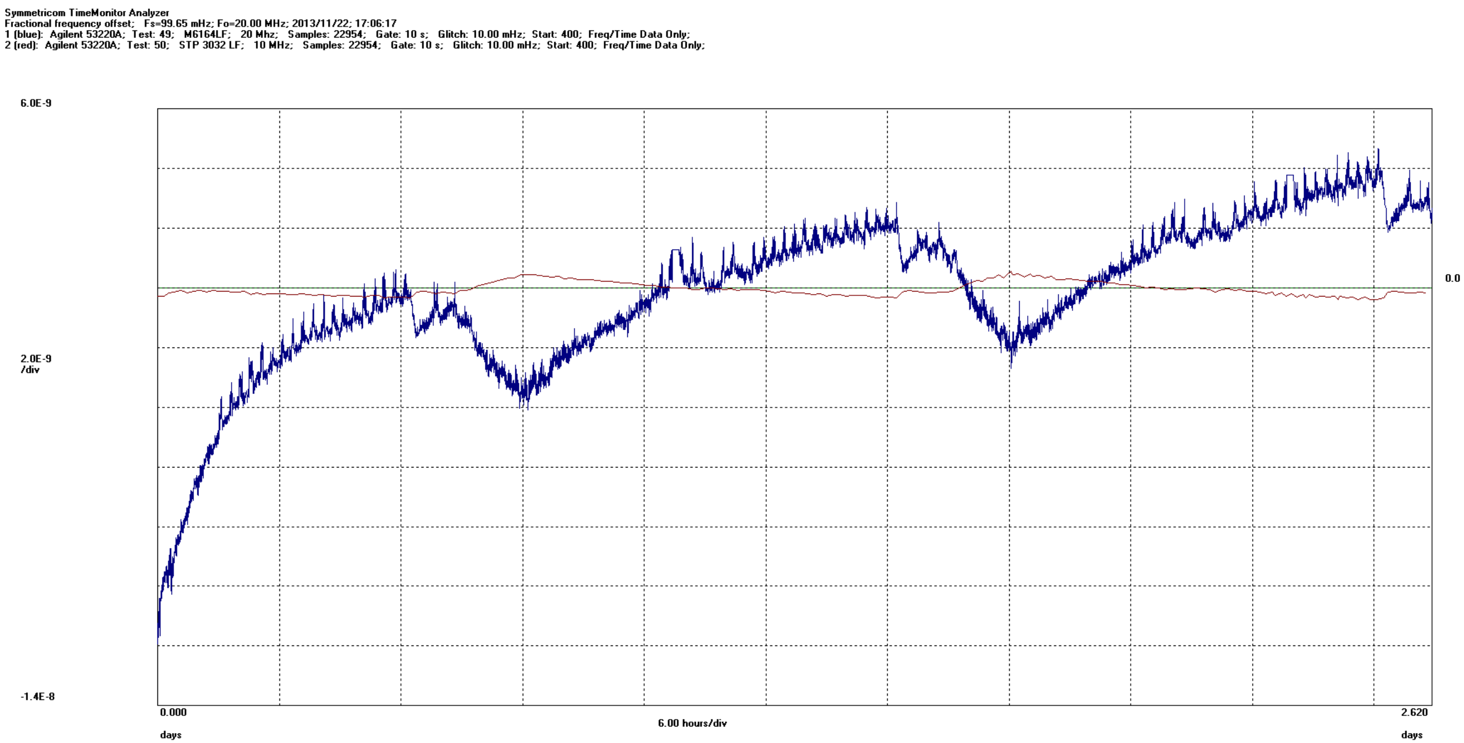
Time and Frequency

- 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.)



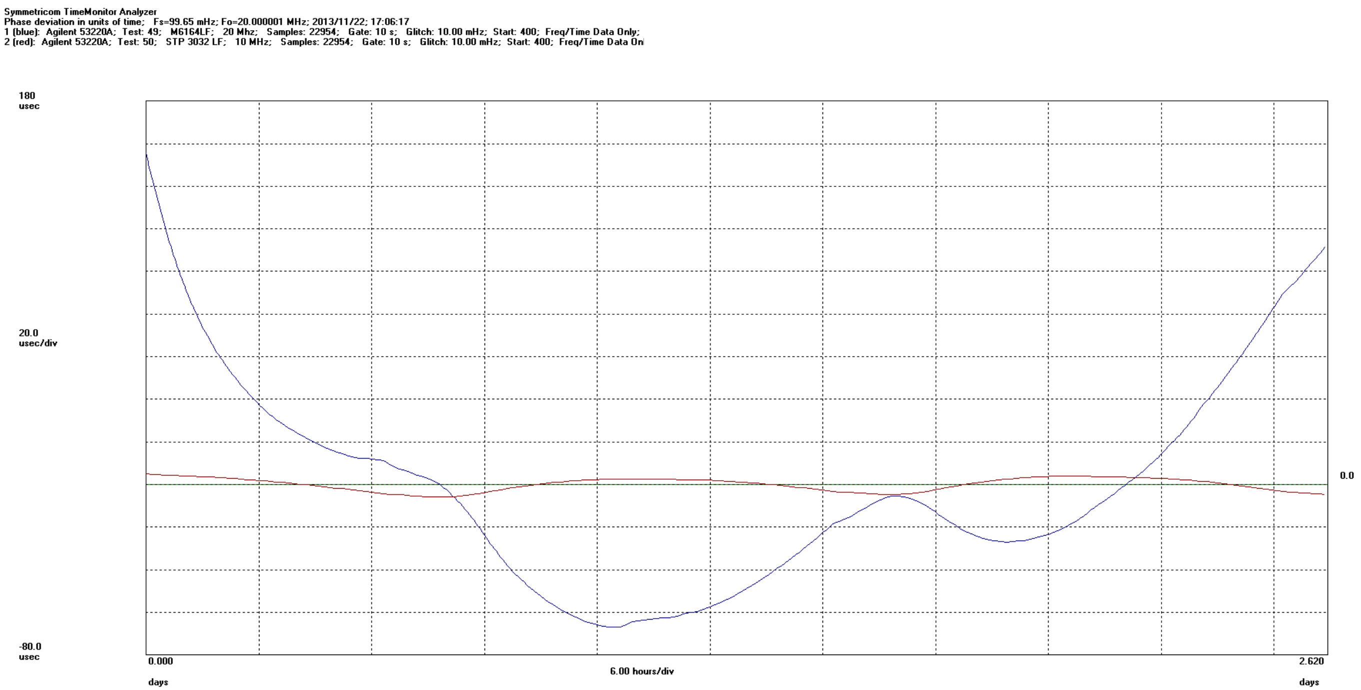
Time and Frequency

- Does an oscillator labelled “10MHz” provide a 10MHz output?
  - Two good oscillators measured over >2 days
  - Frequency is close to 10MHz BUT not exactly equal nor constant



Time and Frequency

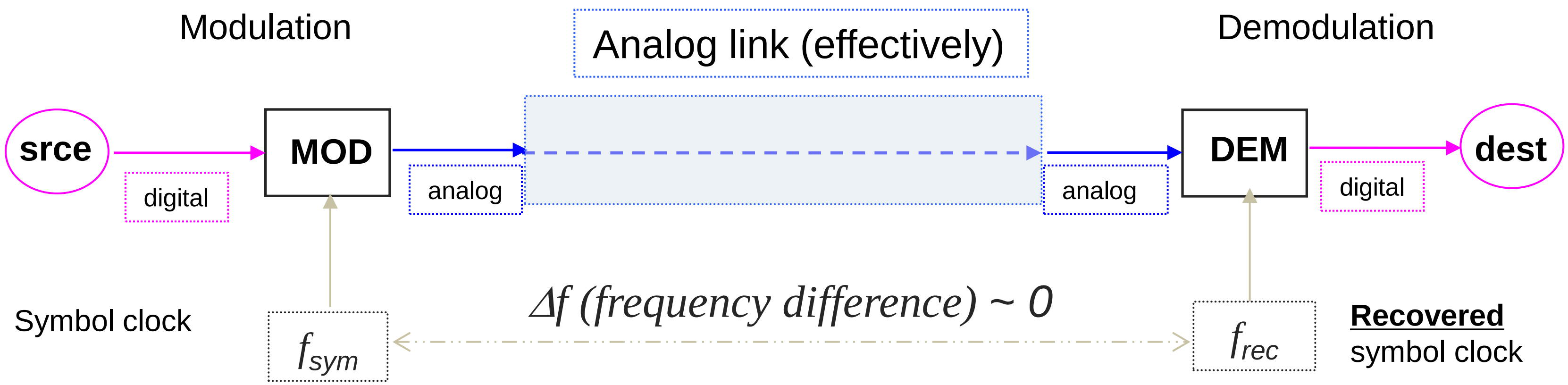
- Does an oscillator labelled “10MHz” provide a 10MHz output?
  - Two <u>good</u> oscillators measured over >2 days
  - Phase error accumulation is small BUT not exactly zero nor constant



Fundamental need for Synchronization

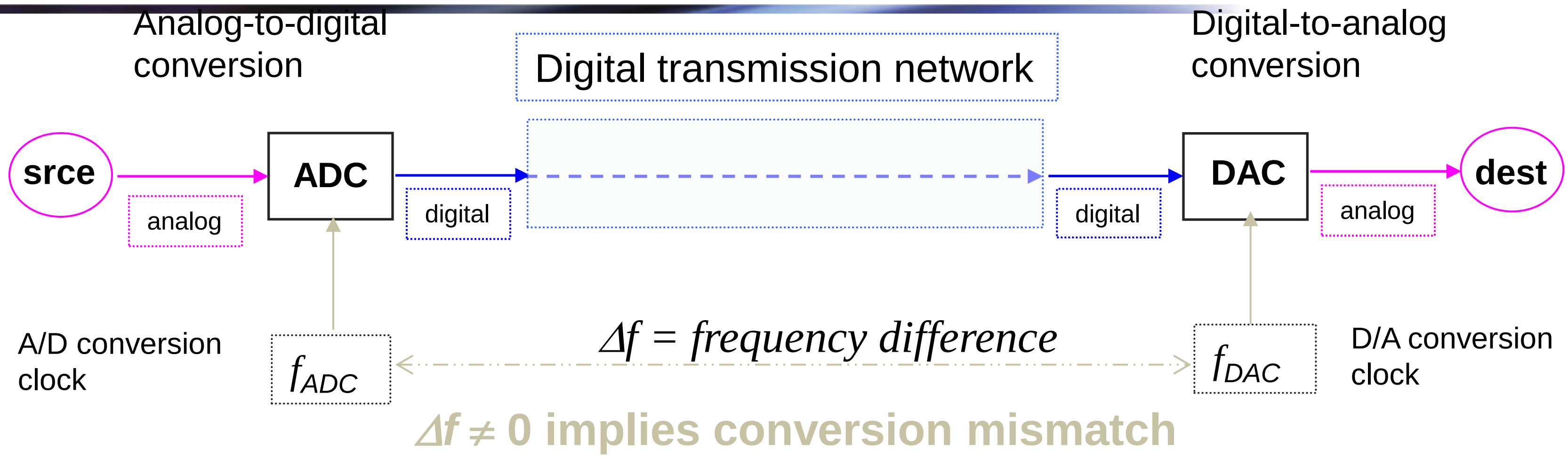
- Timing Alignment is Fundamental in Telecommunications
  - Digital transmission requires symbol-timing alignment
  - Digital network require synchronization to emulate analog channels
  - Circuit Emulation (CBR over packet) requires timing alignment
  - Wireless (Cellular) requires timing alignment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

Data transmission schemes require synchronization



- Source/Destination : modulator and demodulator
- Transmitter (modulator) uses a particular symbol clock
  - receiver (demodulator) must extract this clock ($\Delta f \sim 0$) 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 ($\Delta f \sim$ Doppler)

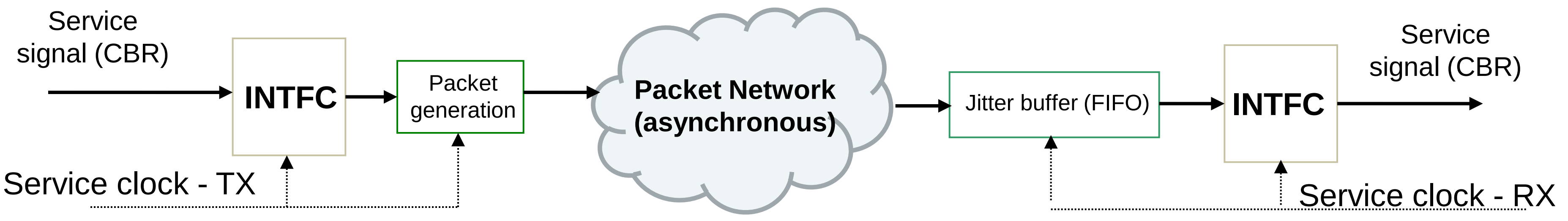
Timing Alignment required in Voice-Band Transmission



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

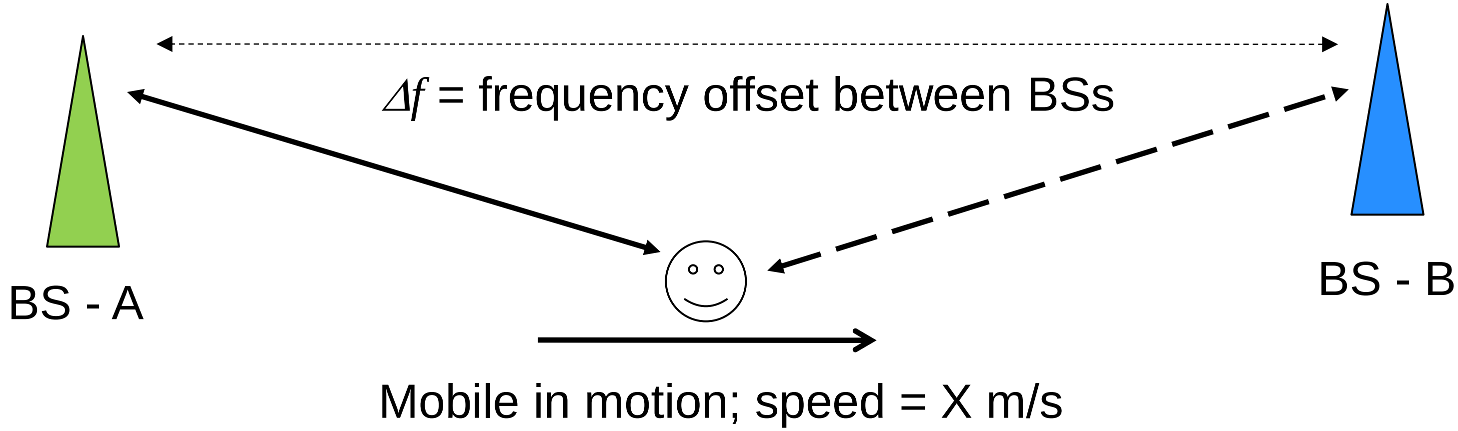
- Source/Destination : Voice/video/fax terminal
- The digital transmission network *emulates* an analog circuit (the original circuit emulation)
- Impact of frequency difference (Δf):
  - Eventually buffers will overflow/underflow (e.g. slips) (“obvious”)
  - Pitch Modification Effect (PME) (analogous 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



- 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

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
- Modern Wireless (LTE) requires stringent timing to support special services/functions
  - BS-A and BS-B can cooperate for providing enhanced bandwidth to mobile
  - Frequency as well as relative phase

Timing Alignment in Multimedia

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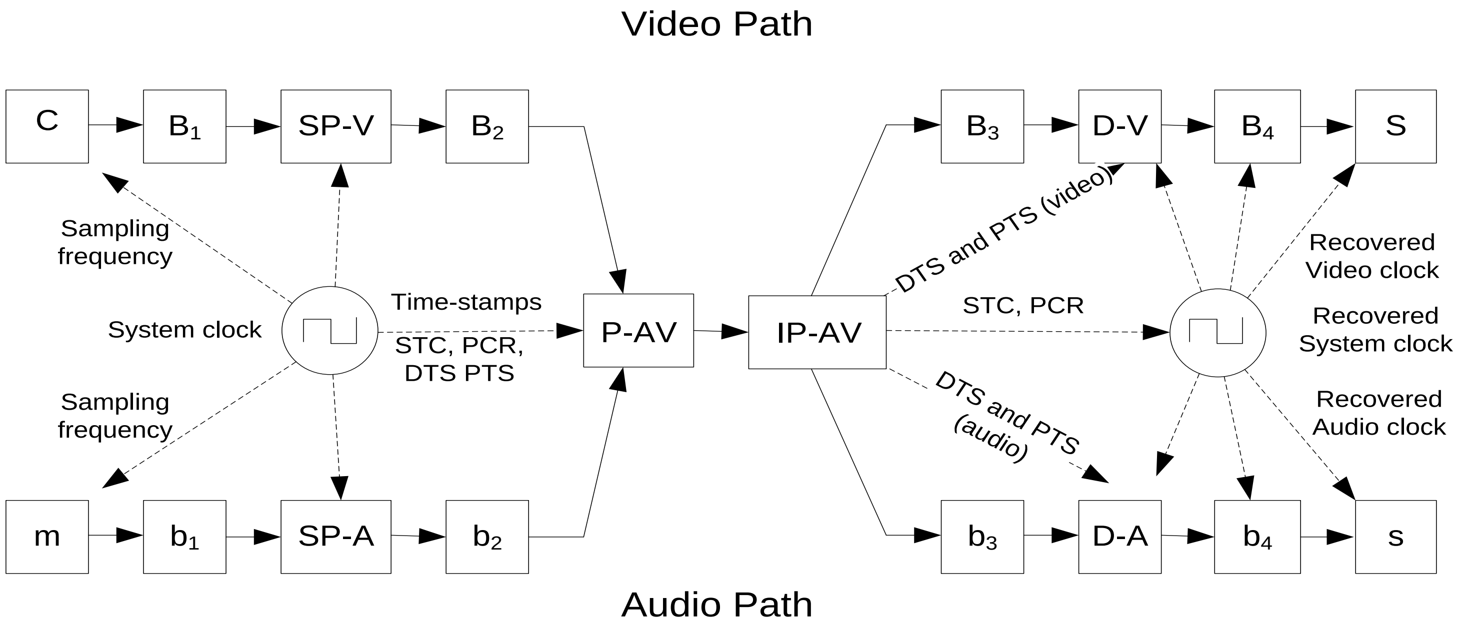

- Frequency offset (wander) between audio and video sampling results in loss of lip-sync
- Frequency offset (wander) between send-side and receive-side system clock results in freeze (video), breaks (audio), and possible loss of lip-sync