Timing aspects of advanced modulation methods

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Outline

- With 5G and new high speed optical systems, bandwidths have been increasing due to the use of advanced modulation methods.
  - What are some of the issues from a synchronization perspective?
  - Has Sync kept up?
  - Do we need changes?
  - Ongoing work in standards to specify high rate bit-rate transport
- Outline:
  - Background leading to current assumptions
  - Evolution of formats (fibre and radio)
  - Concerns: Equipment/Network/specification
  - Summary/conclusions.

Background and historical perspective

- What is modulation, and why sync?
- Modulation is the means by which data is encoded "on the wire". Note: digital modulation only!
- Synchronization:
  - In the general context: this is the need/ability to distribute a timing signal
  - In the context of modulation, this is the function that is necessary to put the data "on the wire".
- Synchronization and modulation are different but are be inter-related.
  - Network sync can aid getting the bits on/off the wire more efficiently(e.g. buffers/pointers) or can have impact on services (e.g wireless handoff.)

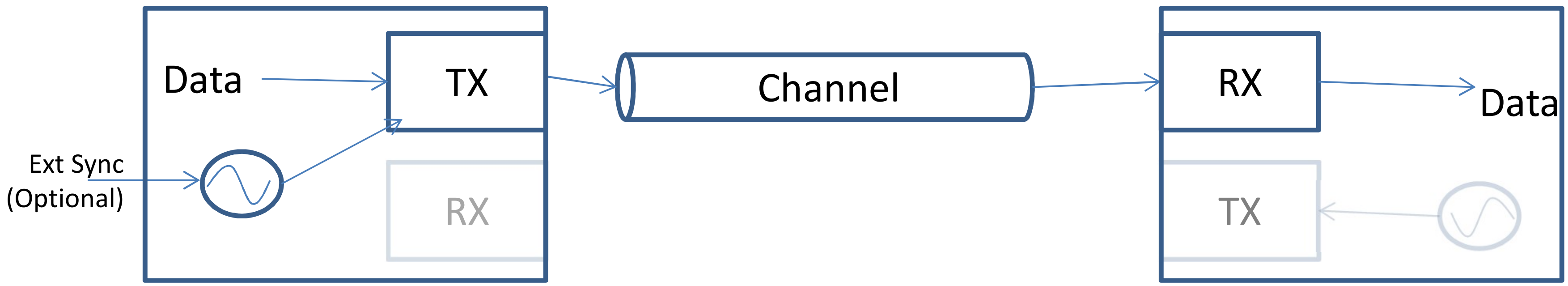
A dedicated synchronization network evolved to support services and infrastructure needs

Current sync requirements

- Fundamental frequency synchronization objective is based on clocks defined to control of jitter and wander in SONET
- Characterized by: MTIE, TDEV (wander), UI rms, peak-peak (jitter)
  - Later expanded to Time metrics (not covered here)
  - Wireless: e.g. 50 ppb
- But, recall where these came from:
  - MTIE/TDEV: need to control pointers, therefore define the noise performance of system clocks (e.g. STR.3)
  - Jitter: control of BER performance and jitter accumulation over a network containing regenerators.
  - Technology basis: SONET, stratum clocks and simple receiver structures (direct detection).
  - All sync requirements traceable to specific system components.

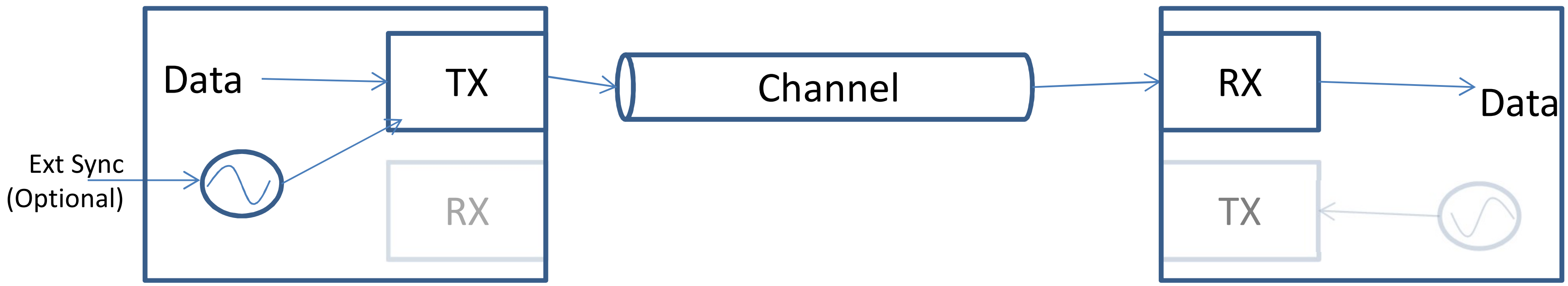
The current specifications are "a line in the ground", but these need to evolve

TX/RX Model (1)



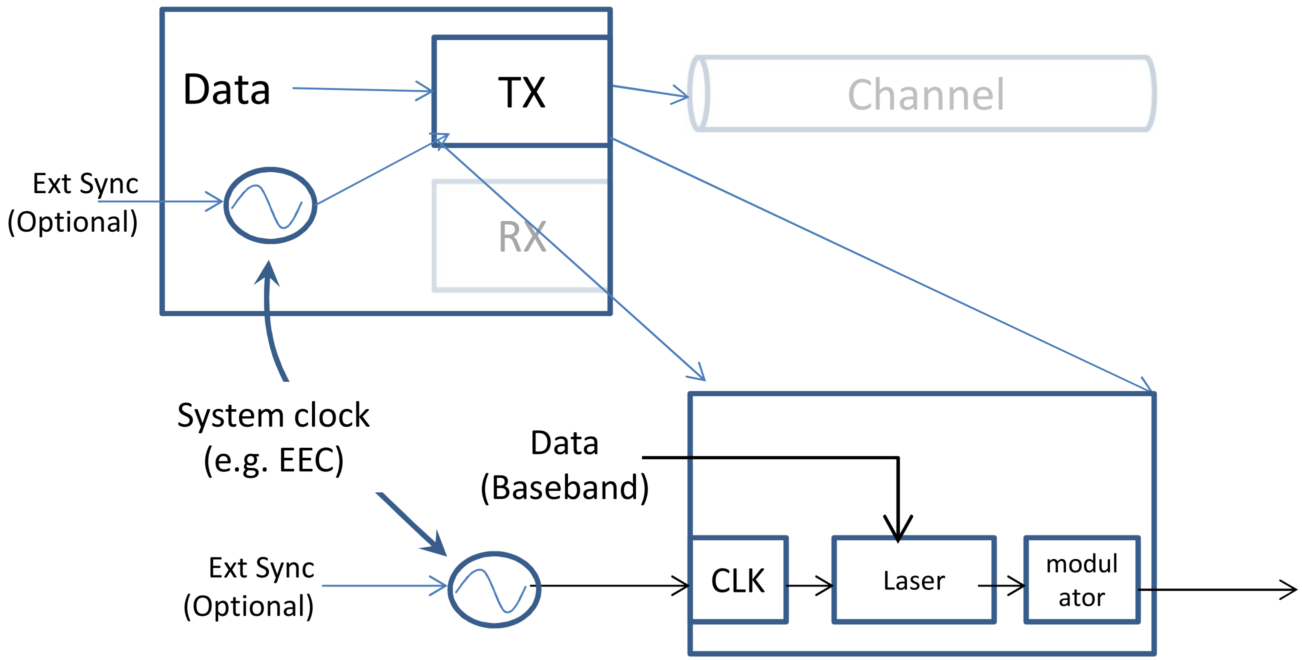
- The base model of a transmission system includes the transmitter, receiver and the channel.
- Depending on the type of modulation, the components will differ.
- The channel model for fiber and wireless are significantly different.

TX/RX Model (2)



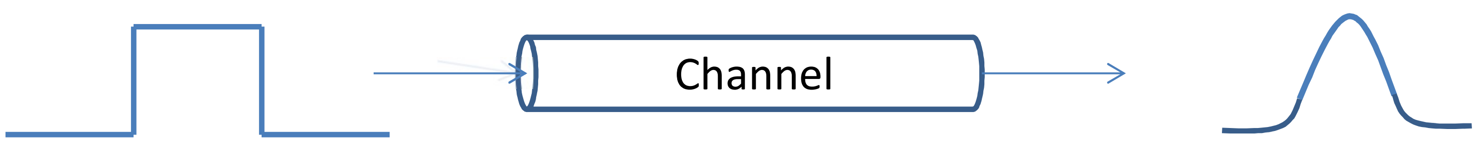
- For existing synchronization requirements, (e.g. SONET), data is directly modulated onto the fiber.
- Specifications assume 3R regenerators. (optical impairments do no impact sync)
- Receiver utilizes direct detection and is generally modeled as a second order PLL.

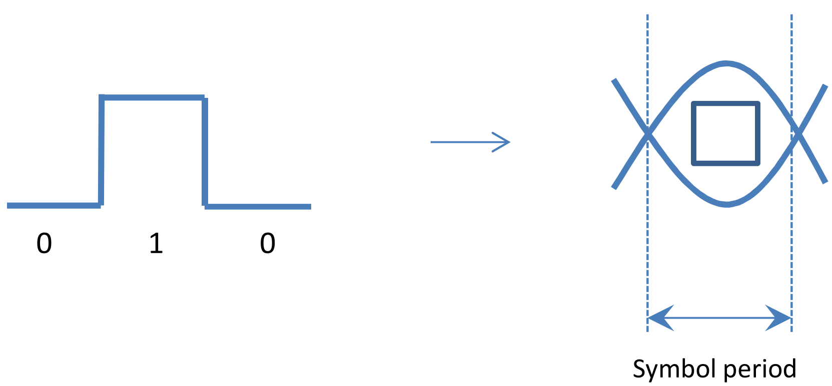
Functions impacting sync: Transmitter



-The transmitter will have an Additional clock driven by the System clock.
-This will impact the high speed (line) jitter.
-Traditionally specified in terms of wide-band and high-band jitter. (scaled based on line rate)

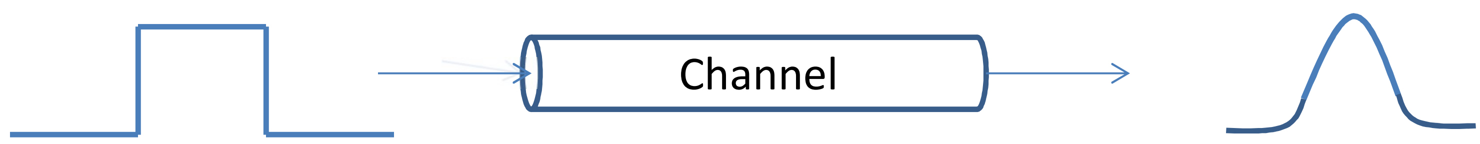
Functions impacting sync: Channel

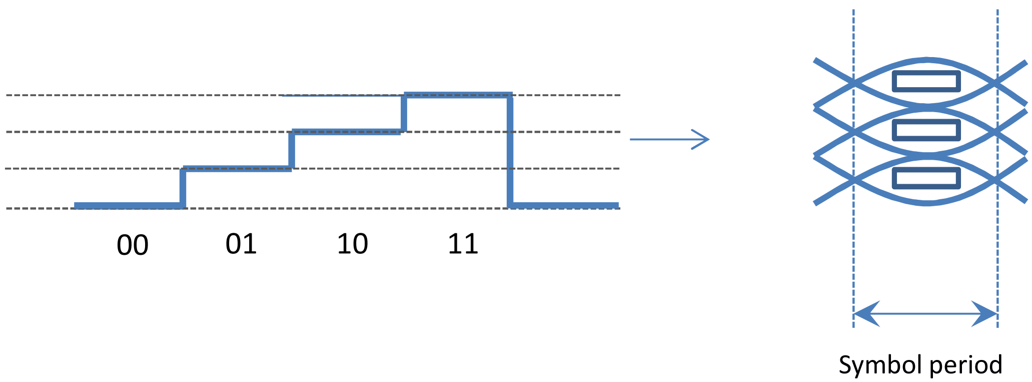




-Channel causes distortion in pulse Shape.
-Receiver clock recovery has to extract clock information from pulse.
-Regenerators may be present
-noise spectrum impacted by various sources, including input.
-classic measure: eye diagram at transmitter to control input (multi-level coding only, e.g. NRZ and PAM).

Functions impacting sync: Channel





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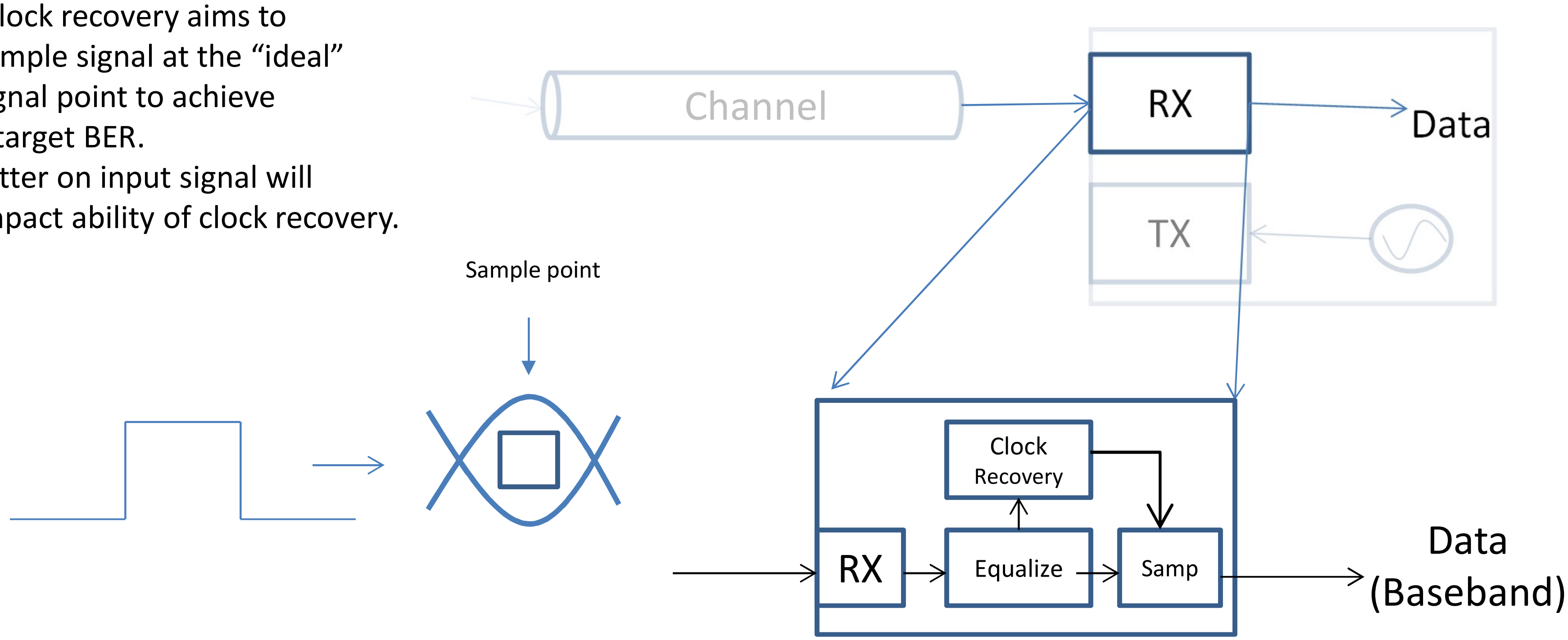
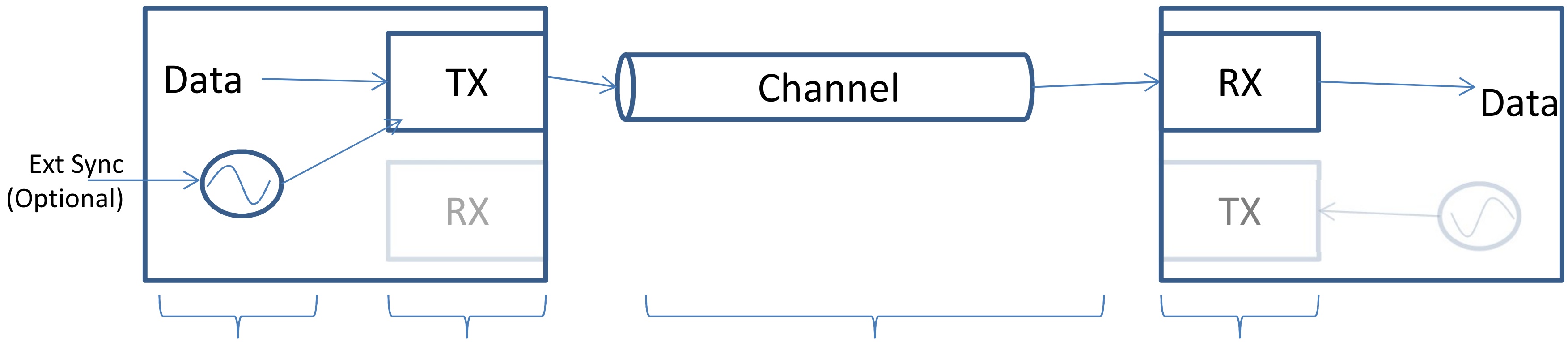
Functions impacting sync: receiver

-Clock recovery aims to sample signal at the "ideal" signal point to achieve a target BER.
-Jitter on input signal will impact ability of clock recovery.



Summary: system impacts



Synchronization:

System clock impacts Jitter/wander	Transmitter: Jitter	Jitter accumulation	Receiver: Tolerance to impairments from the line, Clock Recovery
Sync Metrics: MTIE/TDEV	Sync Metrics: Jitter (peak-peak, RMS), eye	Sync Metrics: Jitter (peak-peak, RMS)	Sync Metrics: Jitter/Wander tolerance (Also MTIE/TDEV if transferring system clock)

Synchronization specs must be coordinated

- Jitter and wander specifications are coordinated for all rates up to 40G SONET. (100G is not defined yet.)
- Generally breakpoints scale with line rate.
- Tolerance is extended to meet MTIE.
- IEEE specifies jitter in terms of eye.
- Current specifications are fully coordinated. (Frequency)

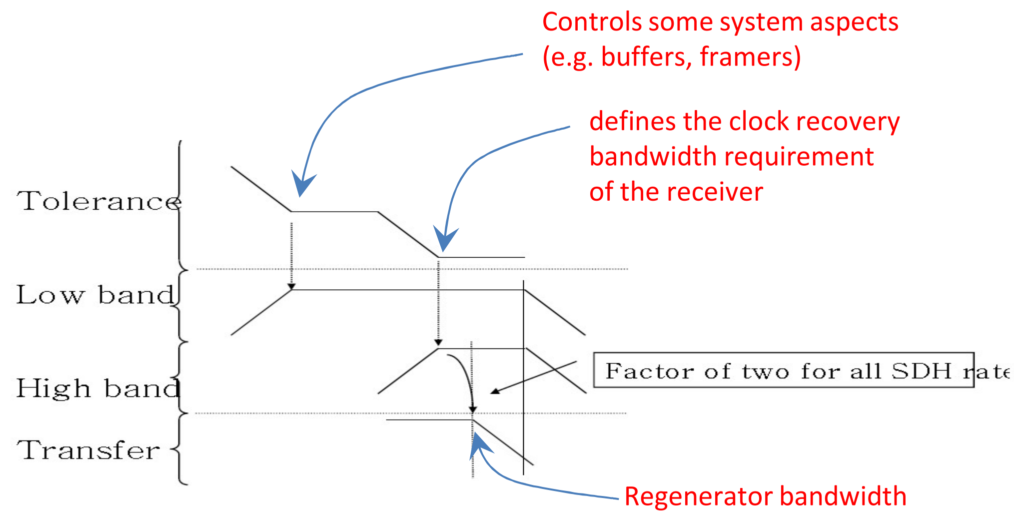
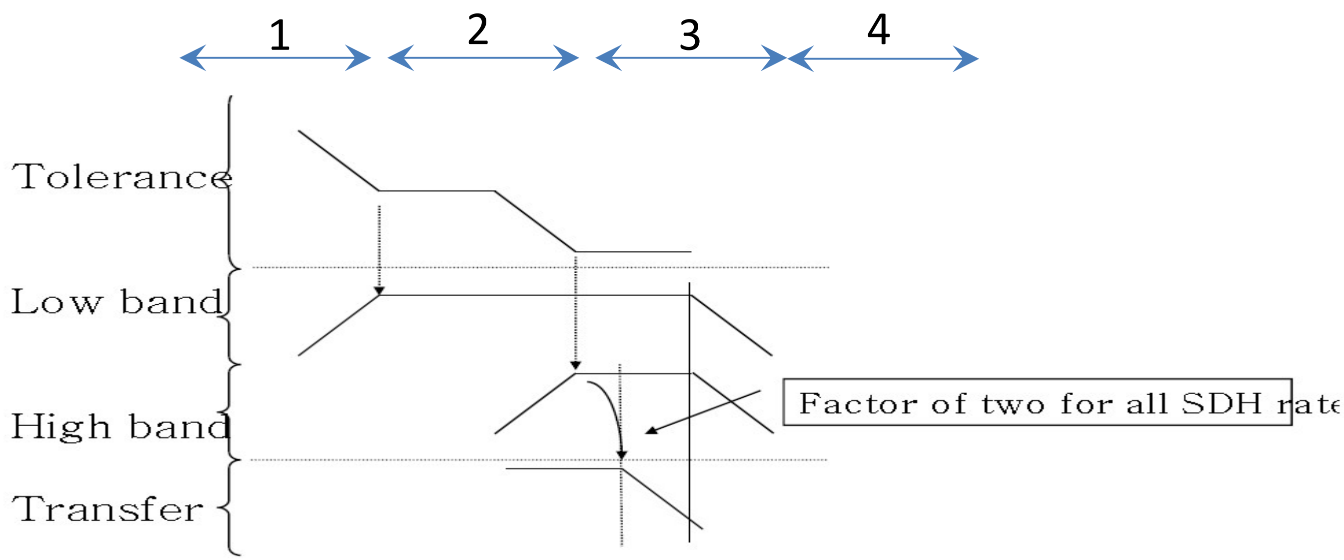


Figure reference:
http://www.chronos.co.uk/files/pdfs/itsf/2008/Day3/TUTORIAL_Use_of_Physical_Layer_for_Frequency_Transport_%28Michael_Mayer,_Nortel%29.pdf

All key network/network element components impacting sync are reflected in specs

ITU Jitter relationships



Jitter/wander causes:
1: network clocks
(MTIE/TDEV not shown)
2: jitter accumulation (regenerators)
3: Transmitter
4: Transmitter (eye)

All noise sources are covered by specifications allowing full control of performance

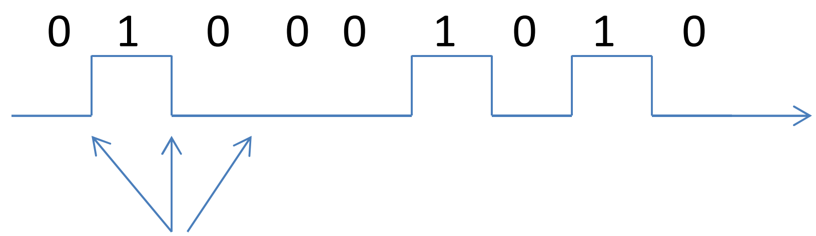
Modulation formats

- Compared to copper, fiber was seen as offering unlimited bandwidth.
  - Need more bandwidth? No problem, increase the bit rate and deal with dispersion compensation.
  - Direct detection systems for fiber are more than adequate for data rates up to 10Gbps.
- Still more bandwidth required?
  - No problem, WDM, but the fiber does start to get to be a problem.
- (Enter streaming video)
  - Now we really have a problem!
- How do you approach the full potential of the fiber transmission channel?
  - Advanced modulation methods (and coding).
  - OFDM, PAM4, NOMA

Increasingly sophisticated modulation methods are being used to increase the capacity of Fibre and wireless systems

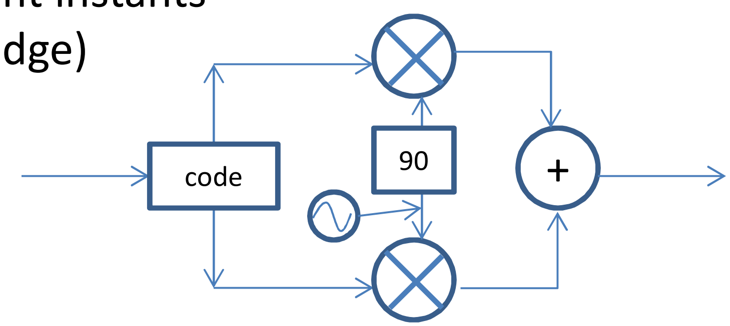
Coding

Direct

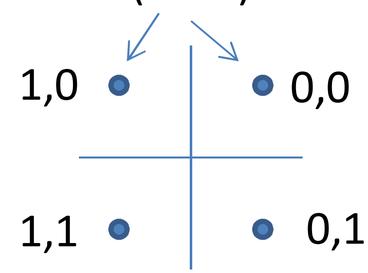


"Significant instants"
(edge)

Phase modulated
(e.g. QPSK)

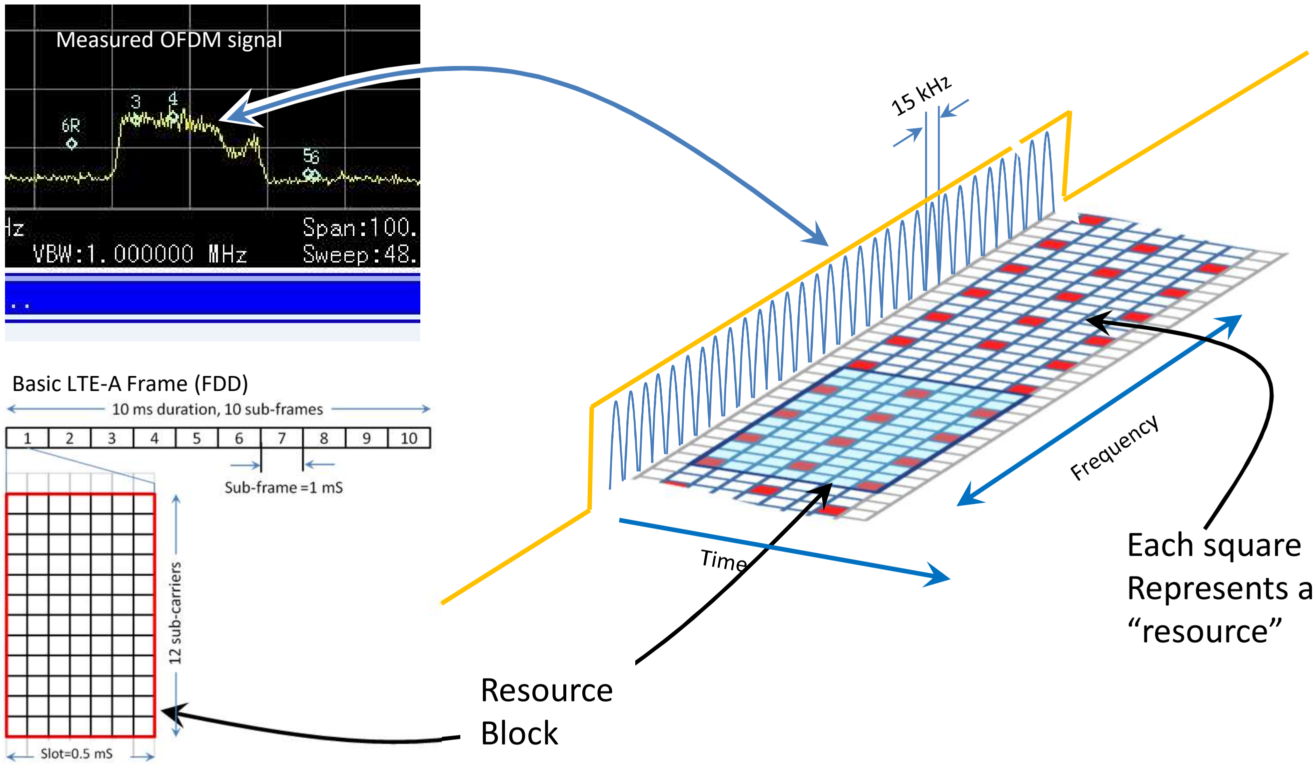


"Significant instants"
(zone)



The concept of "significant instant" has changed

Review: OFDM signal



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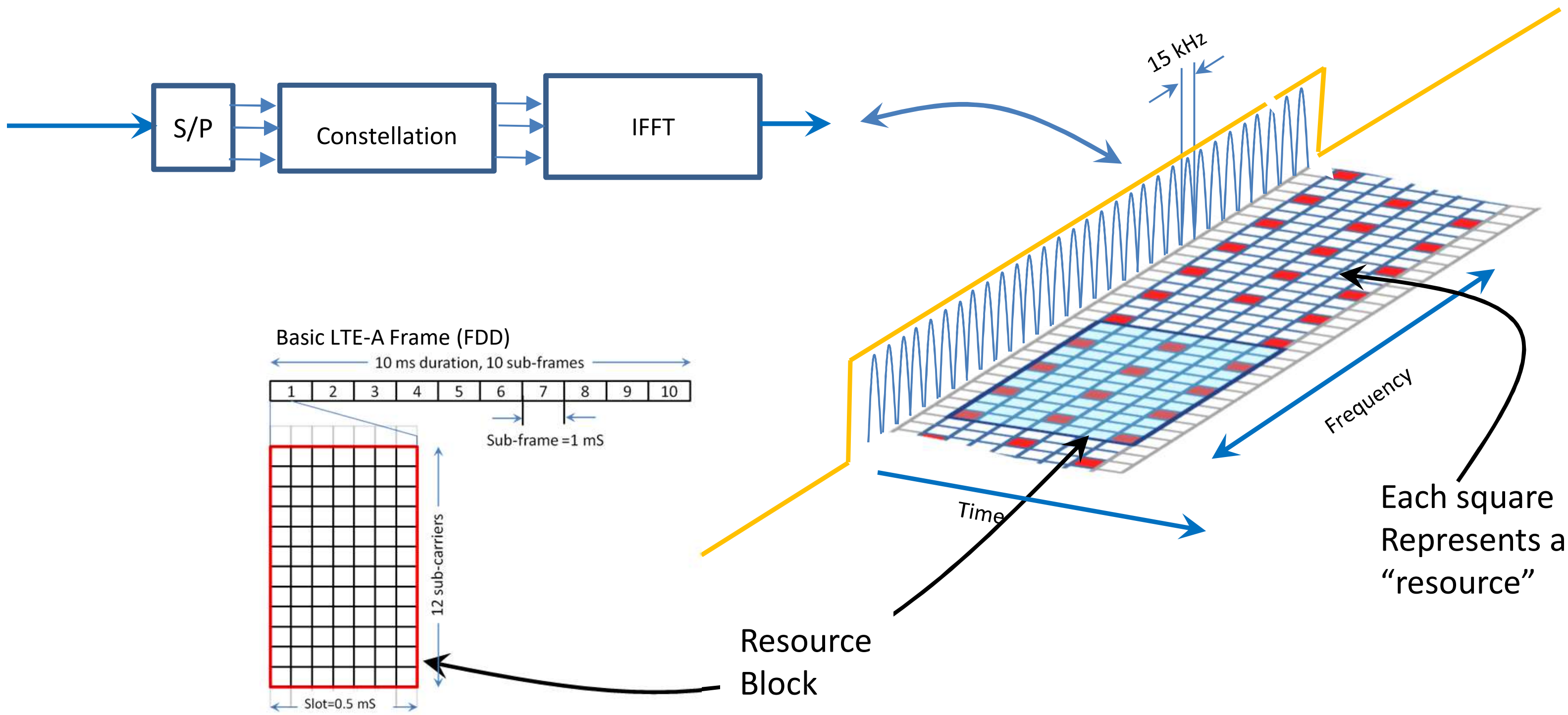
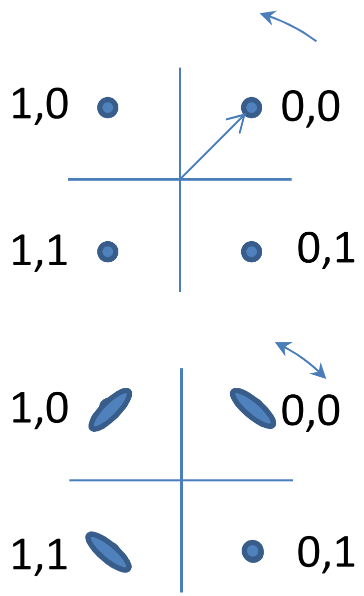


Coding impacts

- Jitter and wander will impact the generation of the constellation.
- Wander will cause a slow rotation of the overall constellation. (equalization should take care of this)
- Jitter can cause spreading of the symbols.



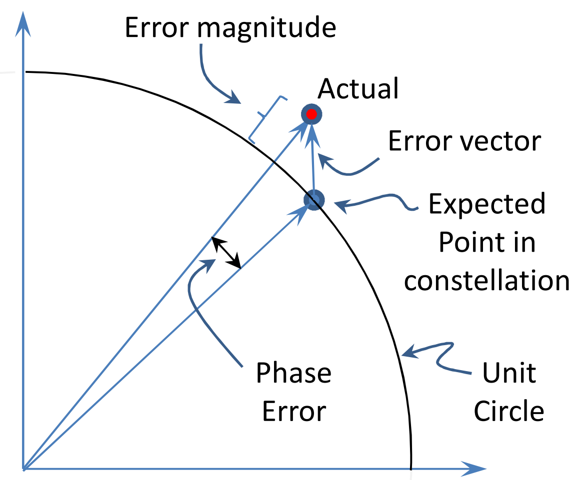
Modulation and other considerations

- Modulation may entail OFDM (in the case of wireless systems.)
- Signal generated by DSP (e.g. inverse FFT, dispersion compensation, etc.)
- DSP also used in optical systems (e.g. dispersion compensation, signal equalization and clock recovery.
- The impact of these components would have some impact on sync, but the architecture is simplified without regenerators.
- Detection (homodyne/heterodyne/Intradyne):
  - Aim to simplify recovery of data in the optical domain.
  - Timing impacts still require study.

- 5G-NR New radio (air interface) definition for 5G defines new "numerology" and has some impact frame definition.
- Current understanding is that sync specifications remain unchanged for 5G (and applicable to LTE) .
- New service requirements (e.g. location) may dominate timing synchronization requirements.

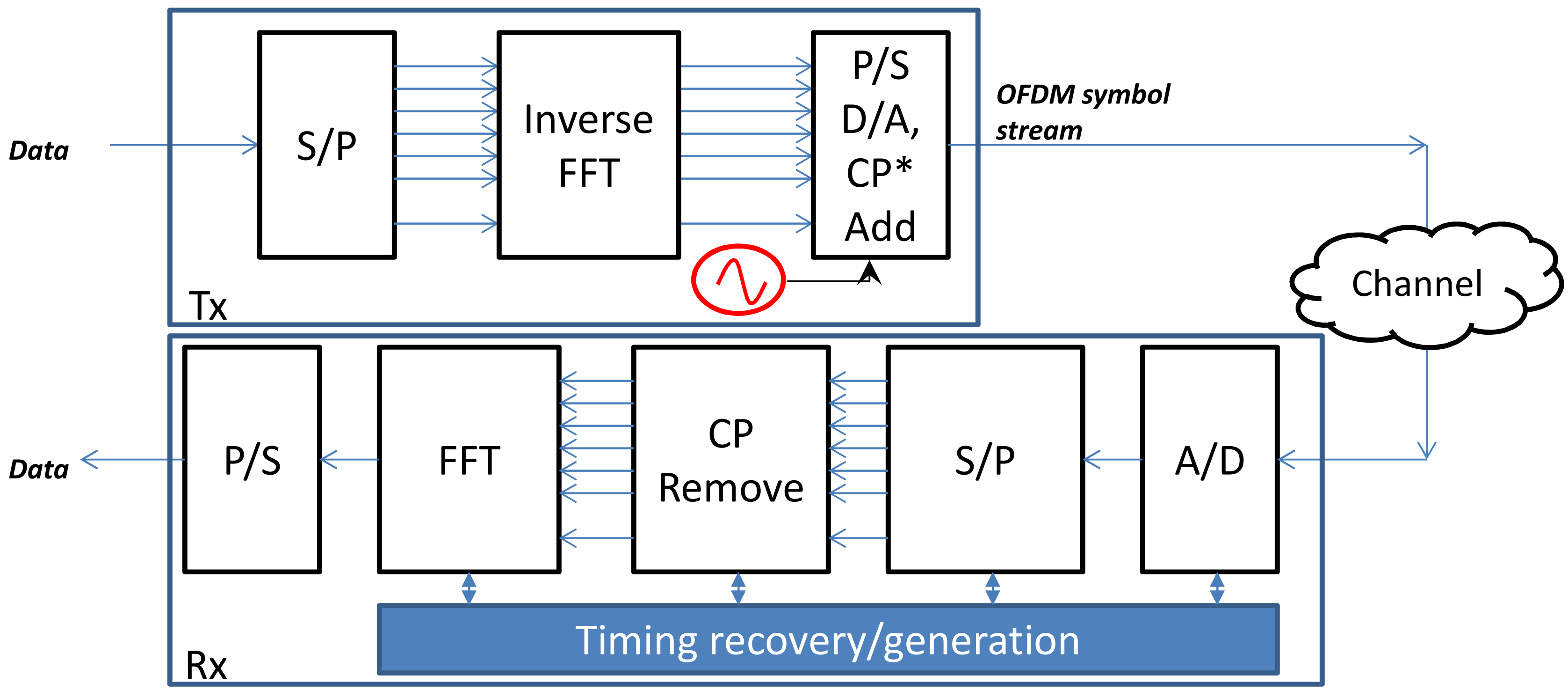
Metrics

- For I/Q modulation jitter measurements based on extending SONET are not sufficient. (and actually meaningless)
- For radio systems, Error Vector magnitude and Global In-Channel Test are used.
- Error Vector Magnitude is a measure of assessing the performance of the coding.
  - Can this provide meaningful information for sync?
  - If so, what would the requirement be?



In developing new metrics all components in the system need to be considered

OFDM component example



*CP: Cyclical Prefix added to reduce ICI

Some Issues

Network

- **Control of jitter and wander now includes additional components.** (beyond the operator's control)
- **Testing jitter**: Traditional concept of jitter testing may not apply. Network design doesn't control jitter to the same extent as SDH/SONET.
- **Testing wander**: Role of network in time/phase distribution shifts testing to wander.
- **Interfaces** where timing may be a concern may now be within network element (e.g. module interface).
- **Architecture** does not necessarily contribute to timing performance improvement as previously.
- **Simplification** of timing distribution may result due to off-loading of some timing issues to vendor.
  - Links don't need to be hand-crafted

Network Equipment

- Simple transmitter/receiver model doesn't fit.
- "Clock" is only one component impacting clock recovery. DSP, modulation are now factors.
- Cannot scale current jitter requirements for some modulation methods.
- Do current test methods reflect actual behaviour in the hands of the user? (e.g. BER)
- Capabilities such as DSP allow can link management and self validation.

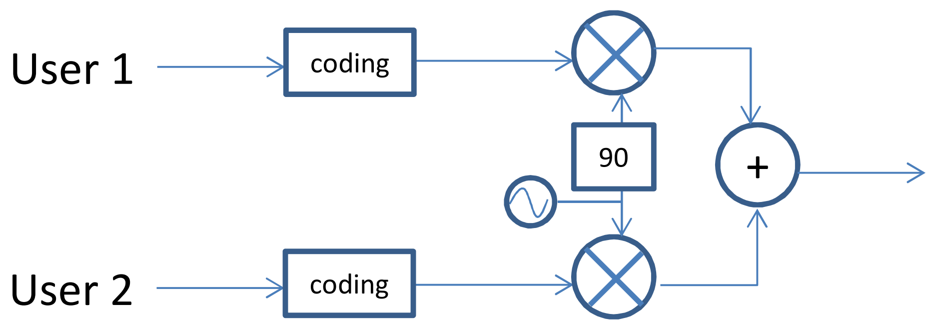
Summary and conclusions

- 5G NR and new Optical line systems increase bandwidths dramatically by using new modulation and coding methods.
- For optical, the tradition of scaling jitter based on bit rate may not be appropriate.
  - Further work is needed to determine if new metrics need to be developed for sync.
  - PAM4 and coherent are on the horizon.
- For jitter and wander, the lack of regenerators in the network architecture simplifies synchronization distribution.
  - The transmitter/receiver module pair will likely be transparent to sync allowing optical links to still play a role in timing distribution.
- For wireless, the existing LTE requirements are seen as sufficient for 5G.
  - There may still be a need for tighter synchronization requirements to support new services.

Thank you

Aside: NOMA

- Non-Orthogonal Multiple Access
  - New study item in 3GPP to get more users on the existing spectrum.
  - Attempt to carry multiple users on the same sub-carrier.
  - Also know in 3GPP as Multi-User Superposition Transmission (MUST).
  - Method employs multiplexing based on power levels.



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Some similarity to QPSK:
Phase modulated
(e.g. QPSK)