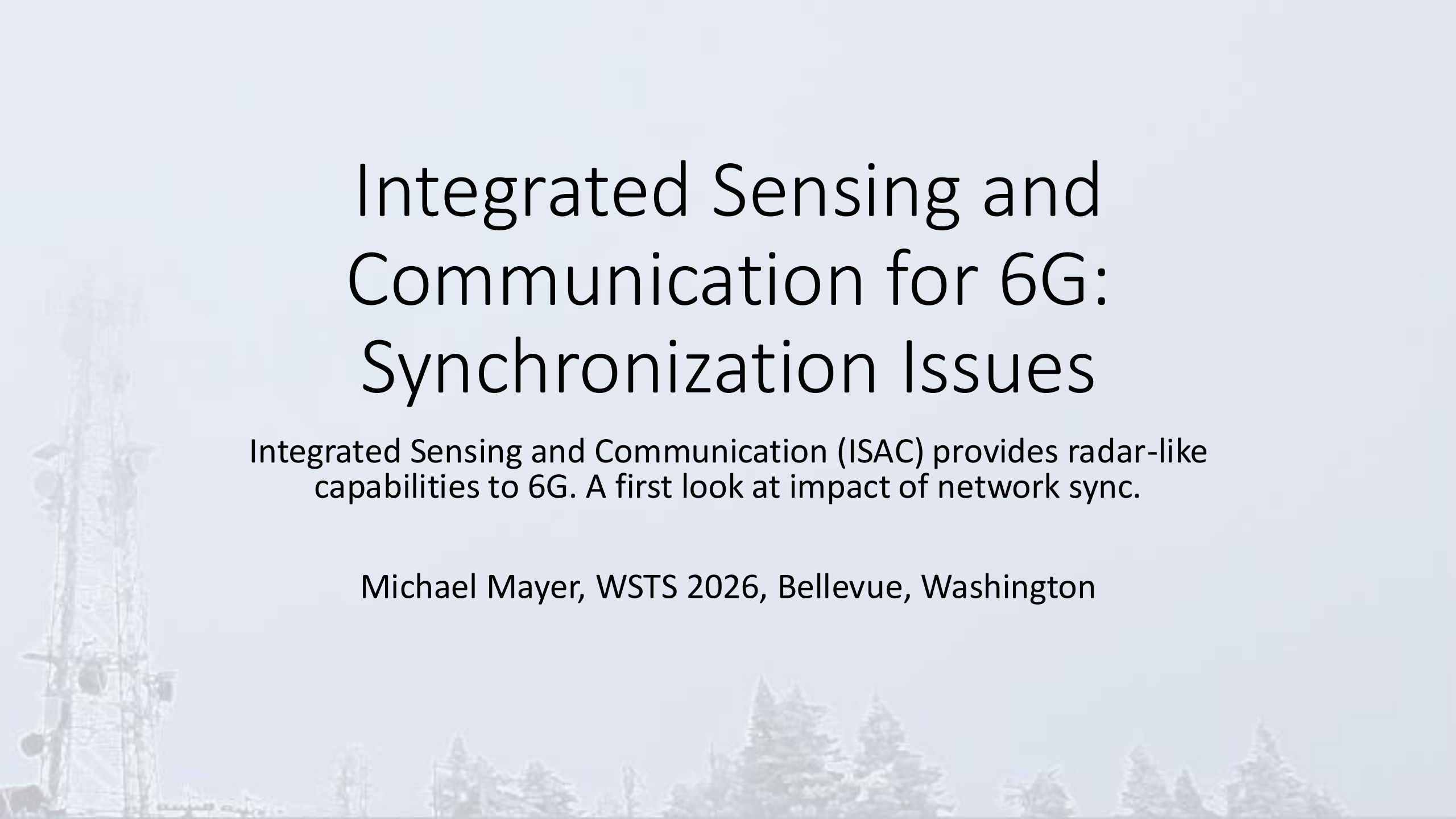


The background of the slide features a faded image of a tall 5G cellular tower on the left side, with several evergreen trees at the bottom. The overall tone is light blue and white.

Integrated Sensing and Communication for 6G: Synchronization Issues

Integrated Sensing and Communication (ISAC) provides radar-like capabilities to 6G. A first look at impact of network sync.

Michael Mayer, WSTS 2026, Bellevue, Washington

Outline

- Description of Integrated Sensing and Communication (ISAC)
 - Recap of some concepts presented at WSTS25
- Extend RADAR sync understanding to ISAC
- Using TDEV to assess sync network impact on ISAC
- Areas that require further study

Intent: Very little study has been done on sync aspects of ISAC. This presents some preliminary thoughts on how the existing sync network may impact ISAC

Recap: Sensing and 6G

- WSTS 2025: 6G and possible sync network implications [1]
- Synchronization “likely” to be an issue for new sensing capability requiring **sub-meter** accuracy
- Related: improved **cm level** accuracy requirement for positioning

Reference:

[1] Will 6G require additional synchronization capabilities? M. Mayer, WSTS 2025

Possible sync network impacts?

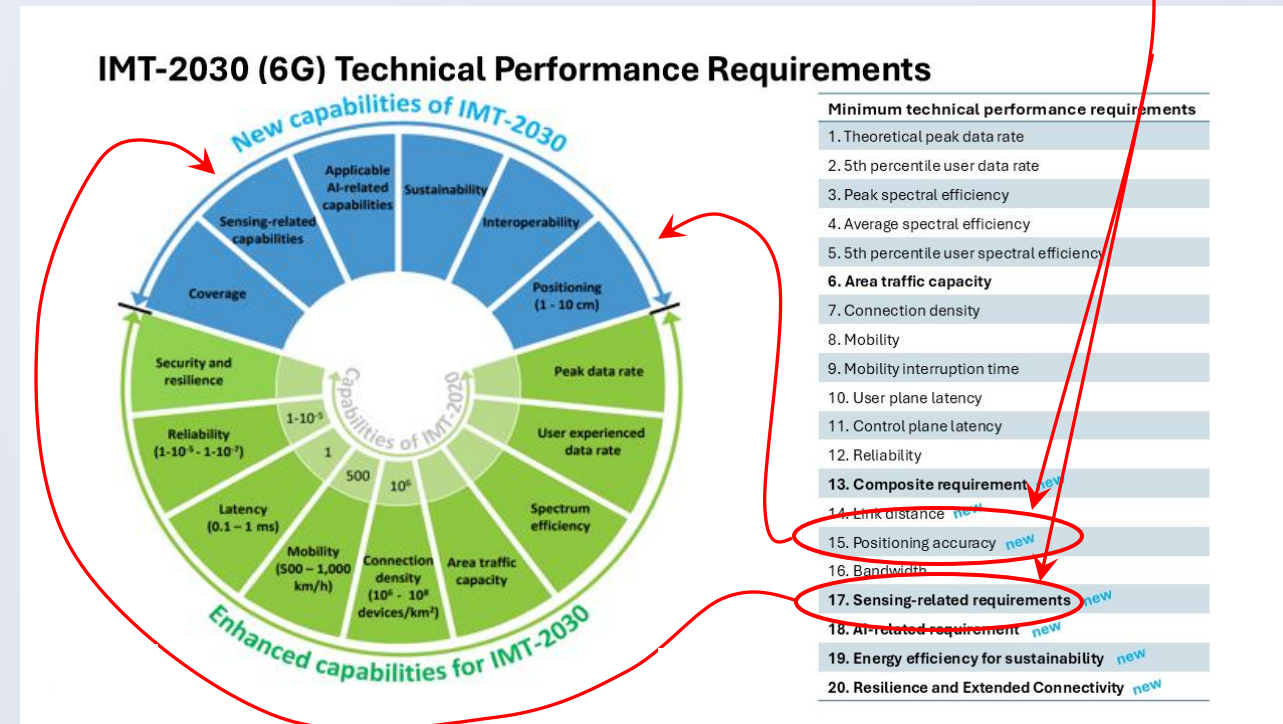
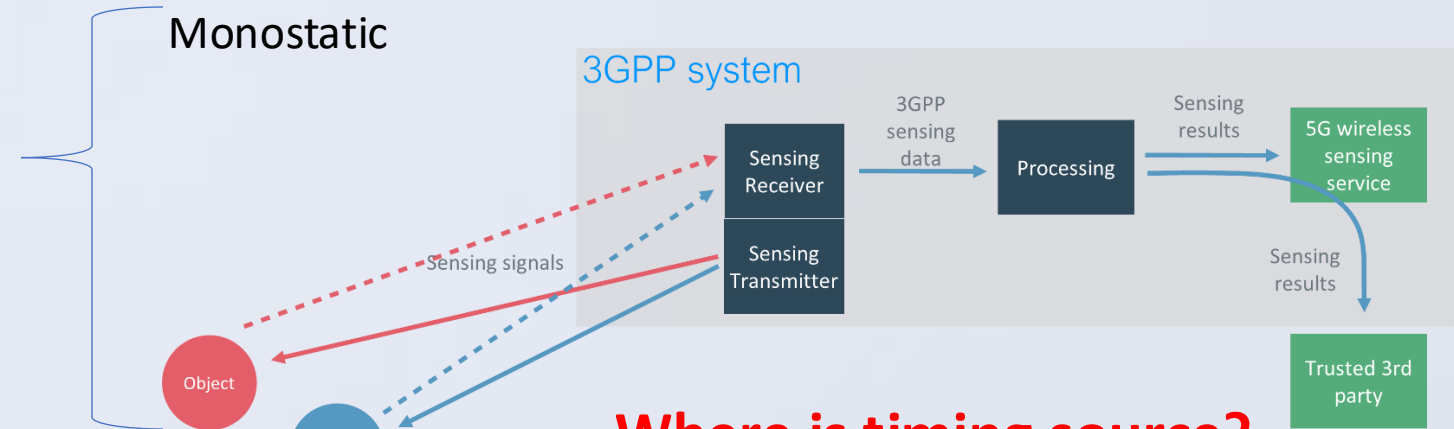
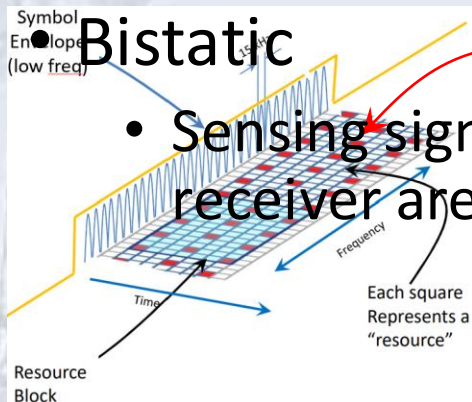


Figure above is from ITU-R M.2160
(used in WSTS25 presentation)

Integrated Sensing and Communication (ISAC)

- Sensing signals (like radar) are provided by the base station
- Monostatic
 - OFDM signal
 - Both transmitter and receiver are collocated
 - Channel state information (CSI) could also be used



Where is timing source?
(Backhaul/fronthaul provides timing)

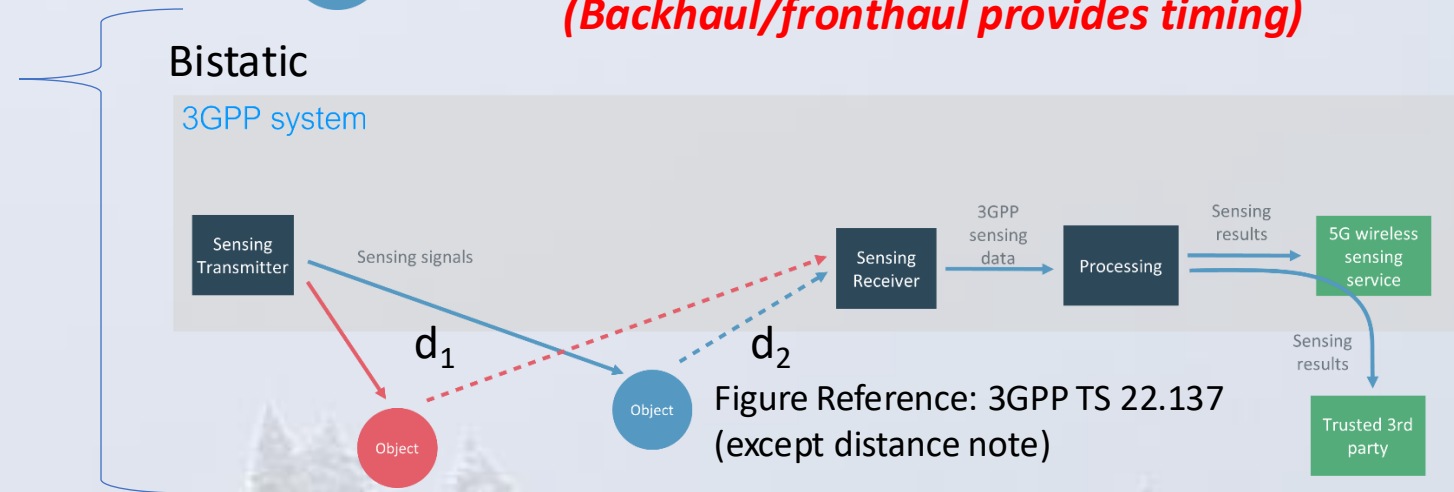


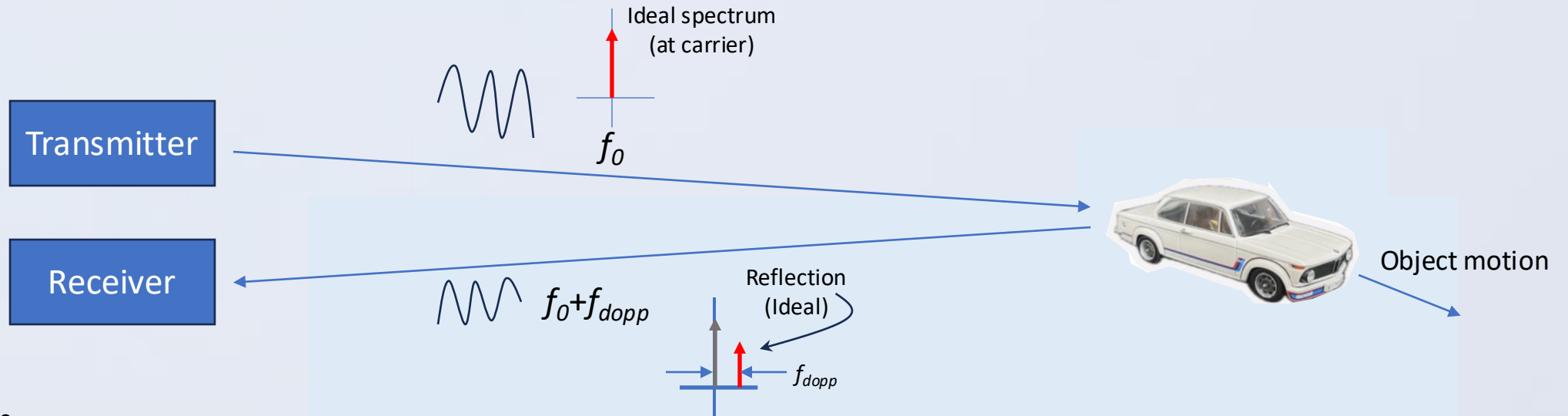
Figure Reference: 3GPP TS 22.137
 (except distance note)

Note $d_1 \neq d_2$

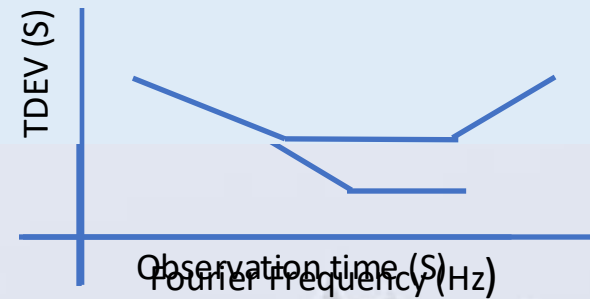
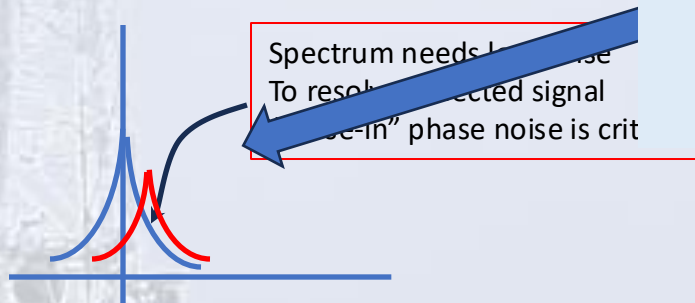
What do we know from radar, and can this be extended for ISAC?

Radar known to be sensitive to phase noise
(excluding time-sync here, but known to be an issue for bistatic radar)

Phase noise is key in radar



Actual spectrum



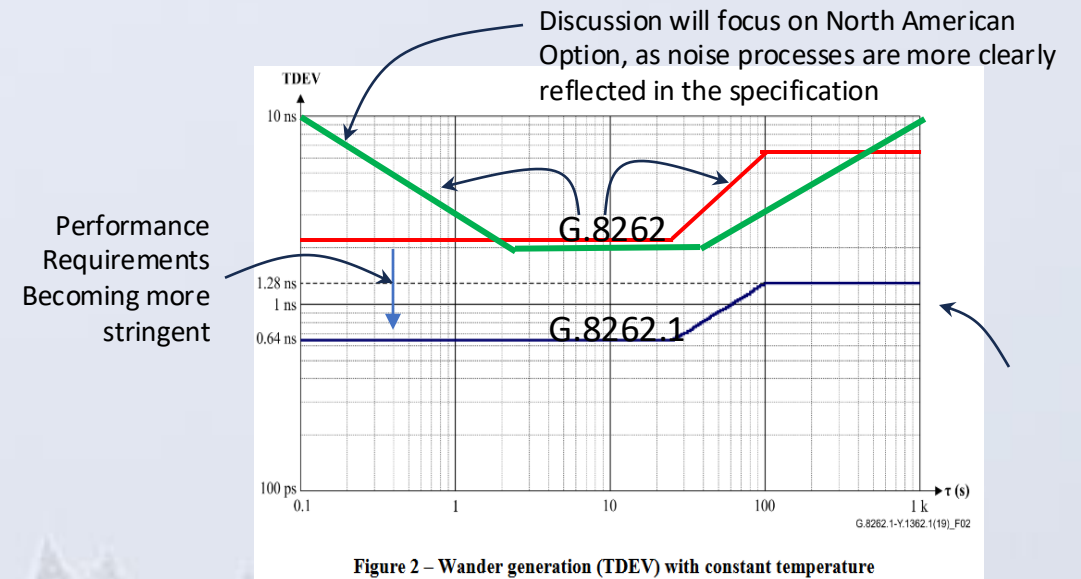
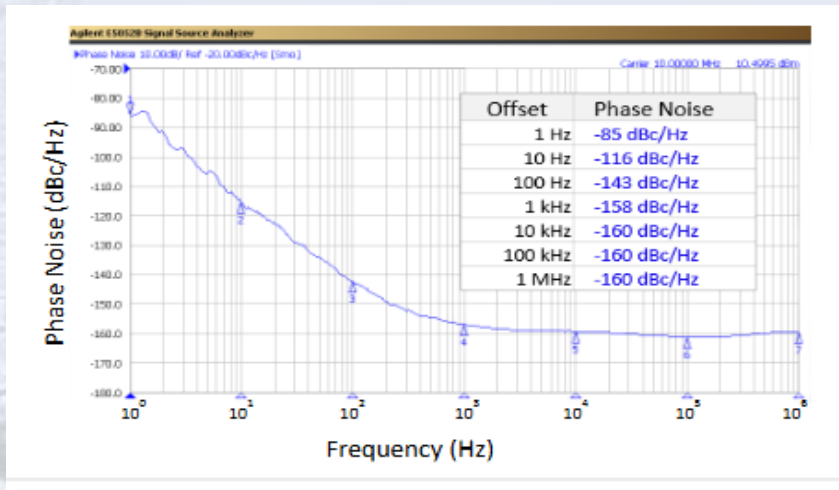
Time domain measure-

- Example: Time deviation
- Based on Modified Allan Variance (MDEV),
- Specific noise processes are reflected by the slope in log/log
- Allows identification of noise
- Frequency domain measures: Power Spectral Density (PSD)
- Stationary noise processes: Allan variance

Phase noise

PSD Example (Specification sheet)

TDEV Example (In standard)

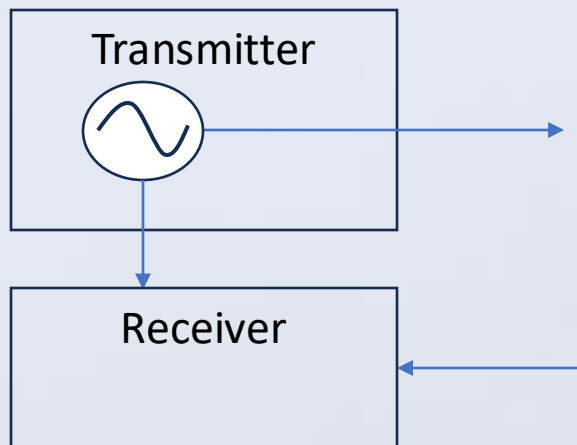


Phase noise correlation used in radar

- Radar system architecture ensures correlation of phase noise between transmitter and receiver

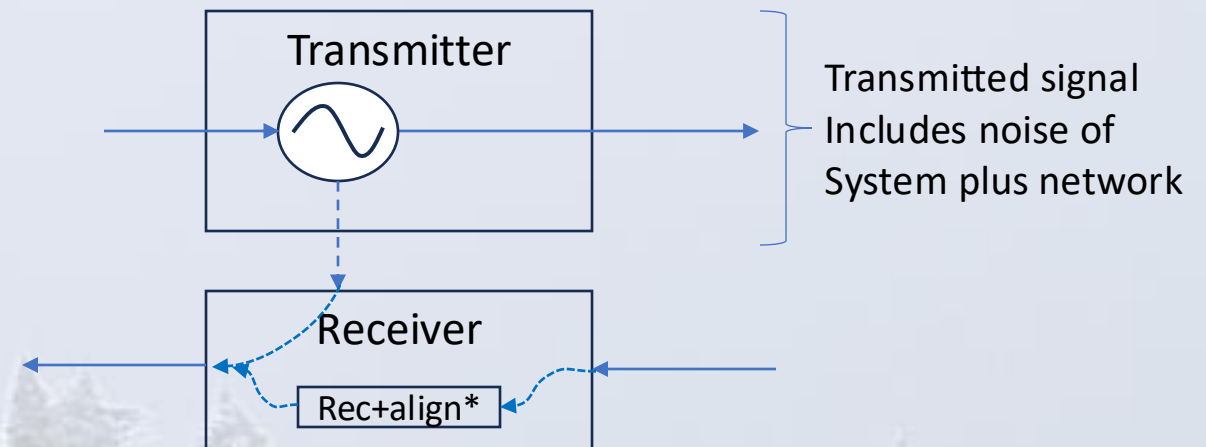
Radar:

Reference for radar receiver
Provided by single transmit oscillator (maintains coherence)



Communication:

Needs to handle multiple clock sources
(includes other functions to align receive with system timing)



*Rec+align = clock recovery and frame alignment

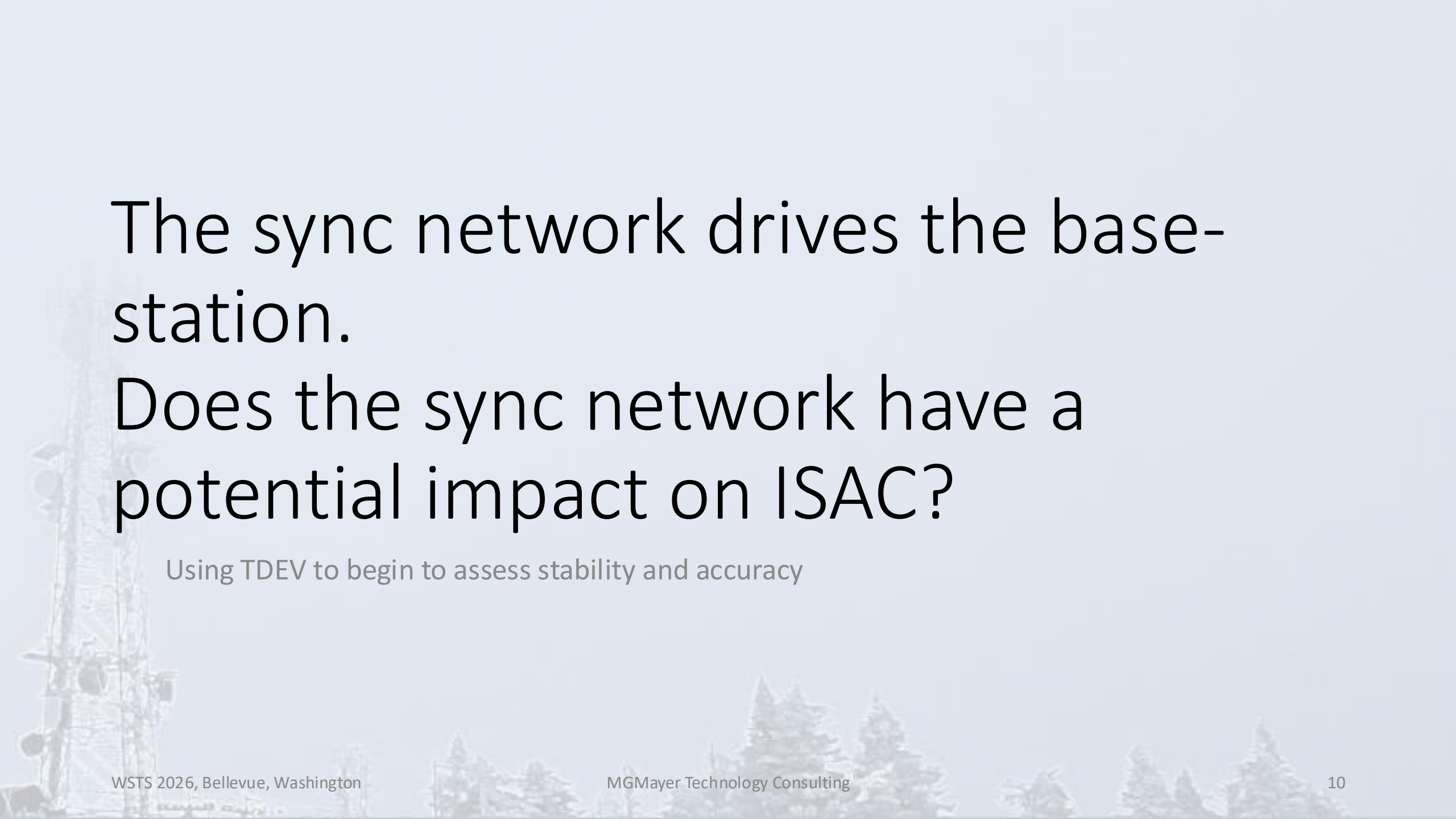
Comparing Systems requirements: communications and radar

Communication system

- Transmitter/receiver pair work together to carry **user data** at a designed data rate
 - Coordinated specification of jitter transmission and receiver tolerance
 - Syntonization and time to coordinate multiple transmitters and receivers
- Desire to provide **error free transmission over a noisy channel**
 - Some mechanisms present to correct impairments
- Synchronization network used to provide support
 - e.g., 50 ppb needed to ensure handover between cells
 - Enabled by a network of clocks (frequency and time/phase)
- Wireless base-station is not part of the sync network
 - “End application”

Radar system

- Transmitter/receiver pair work together to **process the reflected signal**
- Radar system attempts to extract information from noise
- Accuracy may be impacted by the presence of interfering objects (**clutter**) and of the size of the object (**radar cross-section**)
- Low phase noise is necessary
- Measurement resolution may vary with the signal bandwidth
- Signal rate and format establishes usable non-ambiguous range

The background of the slide features a faded image of a tall cell tower on the left side and a line of evergreen trees at the bottom. The text is overlaid on this background.

The sync network drives the base-station.

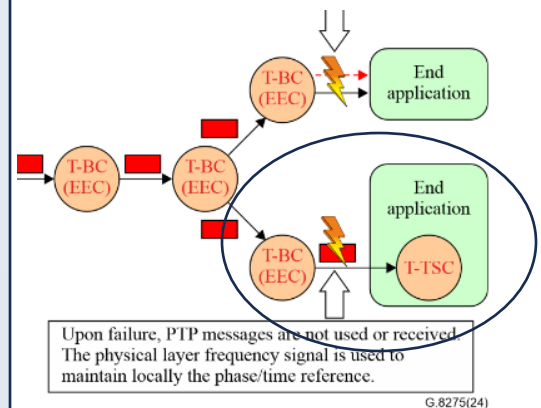
Does the sync network have a potential impact on ISAC?

Using TDEV to begin to assess stability and accuracy

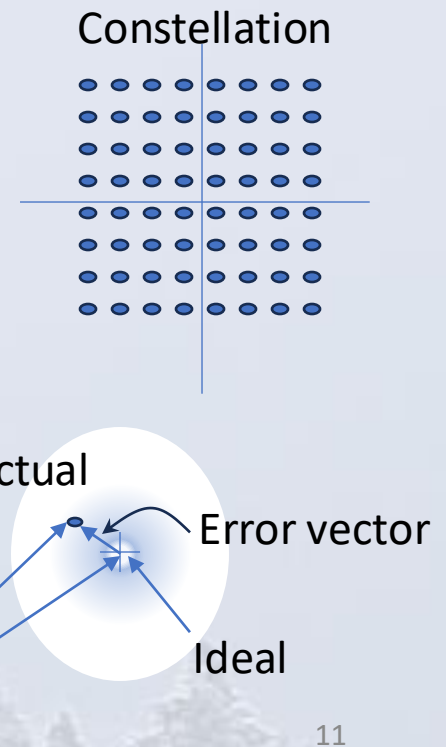
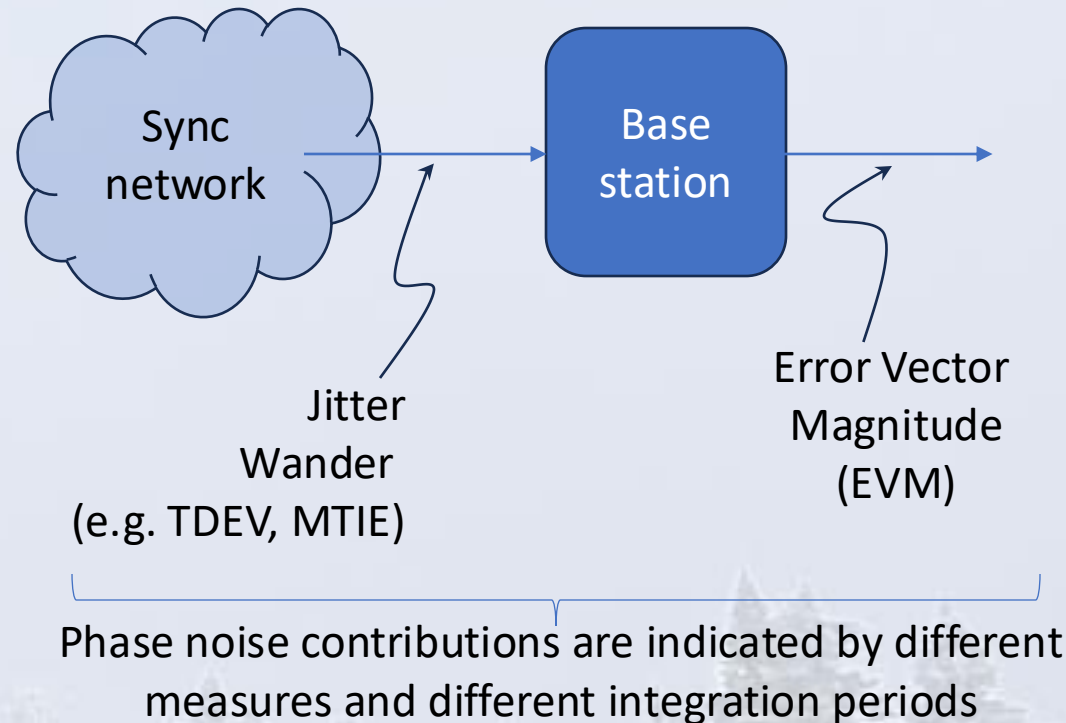
Simplified clock model used to date

- Second order PLL generally assumed to model noise accumulation in the sync network
 - No direct relation between phase noise from network and air
 - Network specifications may not provide enough guidance on impact of clock to ISAC
 - Recall that the base-station clock is *not* fully specified

Note: From G.8275
but focussing only
on frequency distribution



G.8275(24)

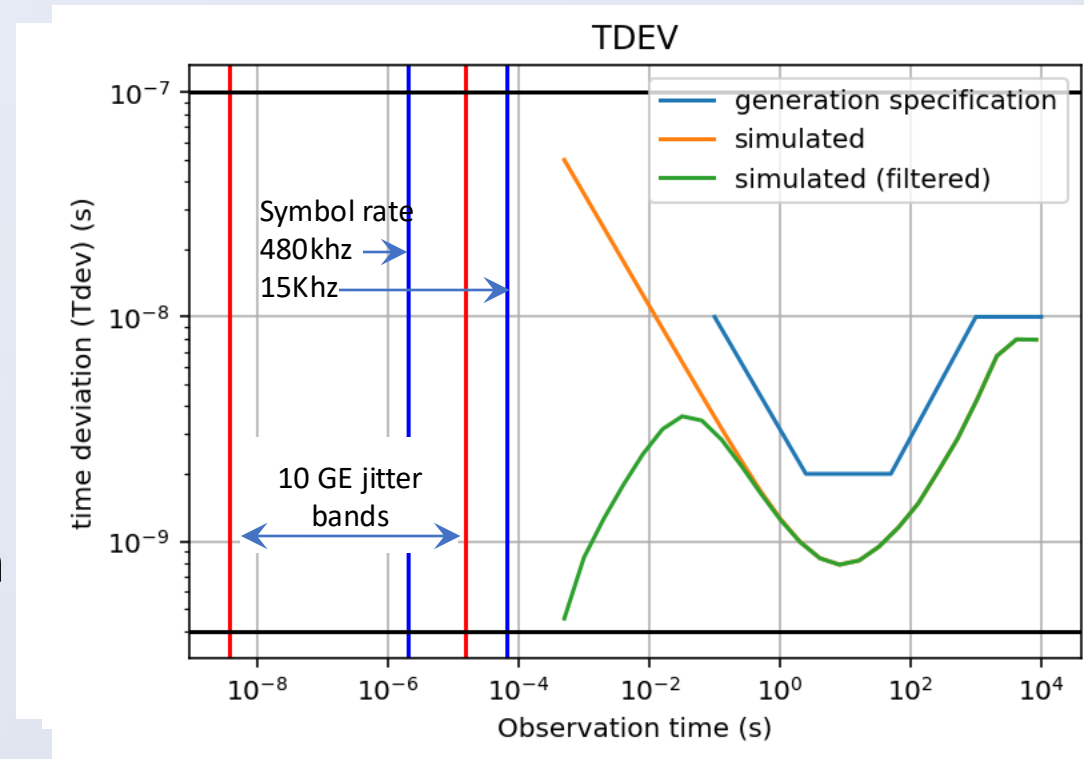


Assessing ISAC base accuracy?

- We know radar is sensitive to phase noise.
- Phase noise in the sync network is characterized in terms of time stability (TDEV)
 - TDEV is a time-domain measure based on modified Allan Deviation
 - Provides RMS error in time over a specific integration time, which will effectively provide and RMS error of distance error
 - System noise (e.g., phase noise in dBc/Hz) can be translated to TDEV
- Can we estimate ISAC accuracy with TDEV?
 - ISAC accuracy will also be impacted by algorithms used but TDEV may establish the contribution due to phase noise of components and the network.
- For ISAC application, choose the observation interval to be relevant to the system to identify RMS error in terms of distance
 - First start: Use OFDM symbol rate, since all subcarriers will be impacted
 - For NR, this would imply a range of $\sim 1.5 \times 10^{-4}$ to 4.4×10^{-6} (SCS from 15kHz to 450 kHz)
 - Alternate: use round-trip time, clock could move between transmit and reception of pulses
 - But neither within the traditional integration range of used for the sync network
 - TDEV measurement filter may hide system noise (and different sampling rate required)

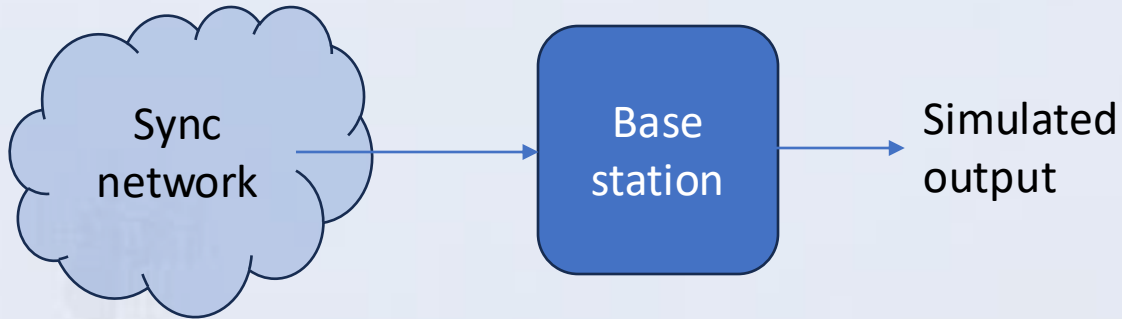
Impact of measurement filter on system noise

- Example: simulated time series, three separate noise processes
- Filtered with TDEV measurement filter (10 Hz)
- TDEV calculated
- Removing filter shows noise processes that exist in system when measurement filter is removed
- For reference: 10GE jitter measurement bandwidth and ODFM symbol rates

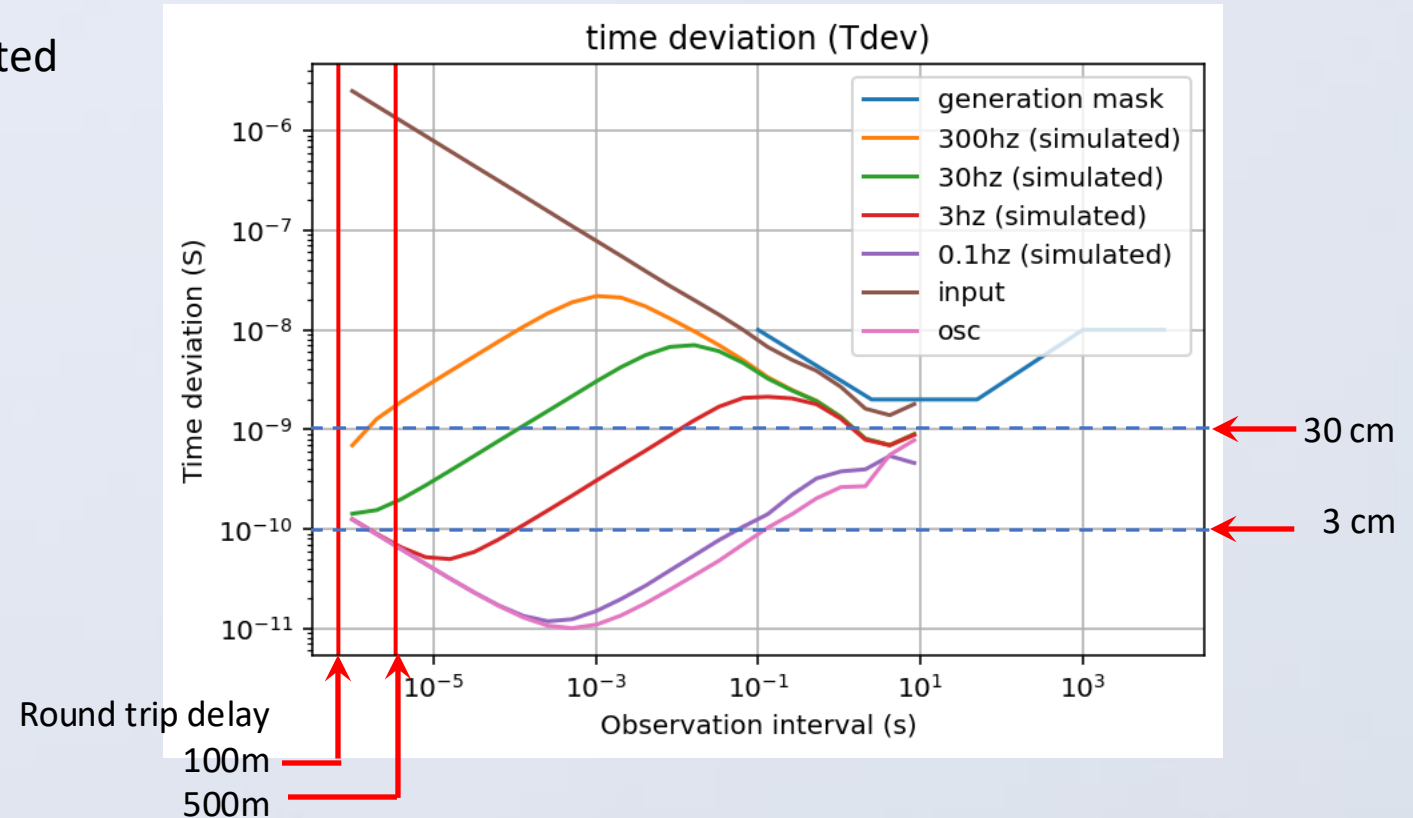


Possible need for coordination of clock and interface noise

Some preliminary simulation results



- **Monostatic:**
 - network input noise based on generation spec
 - System clock based on syncE oscillator, with some increase to accommodate expected system noise
- **Observations:**
 - Base-station timing is largely proprietary designs
 - Base accuracy varies with bandwidth (expected)
 - Some variation Likley due to choice of system architecture
 - Variation possible due to specific NR band used
 - Other system components are expected to add phase noise and impact potential timing stability at the air interface



What are some preliminary areas that may require further study?

Potential sync standardization issues (now addressing new portion of timing spectrum)

Potential Measurement and characterization issues (to support verifying sensing as a service)

Impact of sync: sensing as a service

- Sync network has been developed to support the needs for several technologies
 - Initially TDM, then radio
 - Slips > 50ppb > time/phase
- Sync network performance is directly tied to service performance of user data carried over, or distributed by, the network.
 - Impaired sync may lead to impaired service which can generally be measured (similar for time-distribution, it can be measured independently.)
- Sensing utilizes the network signals but is not tied to an end-user service *per se*
 - Now, sensing doesn't impact an end-to-end user service but introduces a new service paradigm
 - Will sensing as a service require additional support from the network and how?
 - Do we need a new way of looking at sync?
 - Performance may be now tied to the network, do we need to specify the clock (or HRM?)
 - How do we assess performance and conformance, especially if sensing may be required for emergency service support?

Measurement/Conformance issues

Wireless system timing specifications are limited in scope compared to what we are used to dealing with in the timing and sync community

- Main parameters for wireless:
 - 50 ppb (but only over the period of a frame, since corrected by system)
 - Error Vector Magnitude (EVM)
 - 8 ns delay for (CPRI)
 - New specifications TBD for ORAN

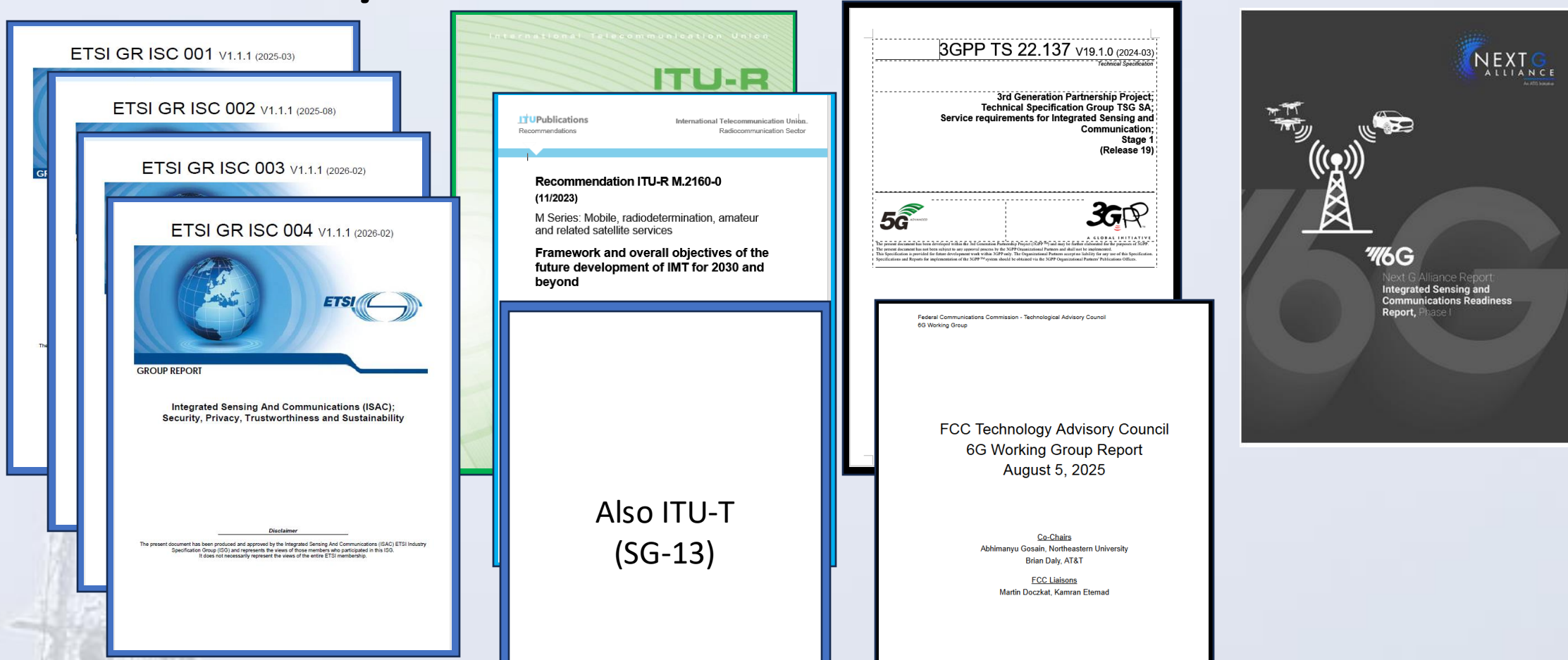
Need to assess Phase noise in finer detail?

- Full timing spectrum needs to cover the appropriate region for ISAC
 - Varies with range (e.g., $2 \times \text{RTD}$) and symbol rate
 - Sub-carrier level processing would be TBD (Need to define how processing at the sub-carrier level would be impacted)
- Use of TDEV:
 - Timing spectrum for ISAC may not be covered by current specifications
 - But measurement requires sampling at rates higher than currently required to resolve the typical 10Hz measurement filter
 - Resolution should also be sufficient to resolve sub-nS phase
 - TDEV does appear to be useful in simulation situation

Summary

- ISAC work is rapidly approaching normative standards development stage
- While “under ideal synchronization” has often been noted in the research literature, there has been little formal work to understand if the network synchronization layer contributes
- TDEV could be used to estimate the base-line accuracy of a wireless system, but further work is needed
- Some areas of further work include:
 - Improved understanding of ISAC measurement algorithms and range requirements/limitations to determine sensitivity to timing
 - Establishing a suitable phase noise model (reference system) for base-station clocks
 - Continuing to study/evaluate measurement requirements for Sensing as a Service
 - Extend discussion/analysis to cover time-sync impacts for ISAC (bistatic case)

Industry interest continues to increase...



Target date for 6G system deployment is 2030

- End -

Accuracy requirements

Seven separate service categories cover three service scenarios:

- Object detection and tracking
- Environment monitoring
- Motion monitoring

Performance defined in terms of

- Accuracy of positioning estimate
- Accuracy of velocity estimate
- Confidence level
- Sensing Resolution
- Missed detection probability
- False alarm probability
- Max sensing service latency
- Refreshing rate

Example requirements (see TS 22.137 for complete table)

Scenario	Sensing service category	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)	
			Horizontal [m]	Vertical [m]
Object detection and tracking	1	95	10	10
	2	95	2	5
	3	95	1	1
	4	99 for public safety, otherwise, 95	0.5	0.5
Environment monitoring	5	95	10	0.2
Motion monitoring	6	95	N/A	N/A
	7	95	0.2	0.2