Features for mmW Distribution Network Use Case

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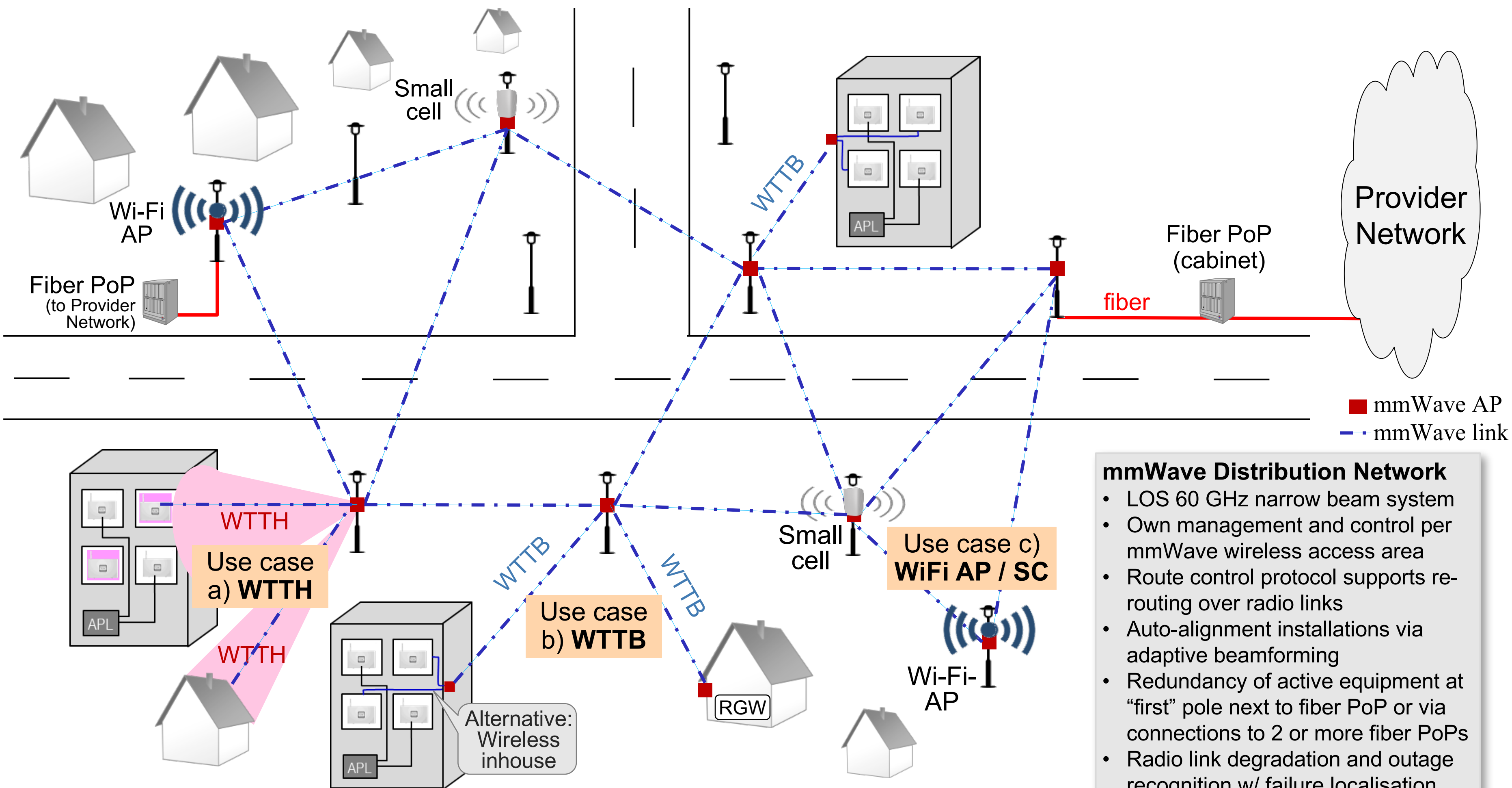
Abstract

- **Contribution in [1] introduced the initial set of changes to IEEE 802.11ay [2] in support of mmW distribution network use cases [3]**
- **This presentation introduces additional details to illustrate example L2 features important for [3]**
  - **TDD/TDM slot structure and dynamic L2 scheduling support**
  - **Beamforming (BF) acquisition for network (NW) initialization**
  - **Periodic Beamforming and Interference scan**
- **We are soliciting feedback to enhance these features and encourage technical contributions to help the standardization of mmW distribution network use case**

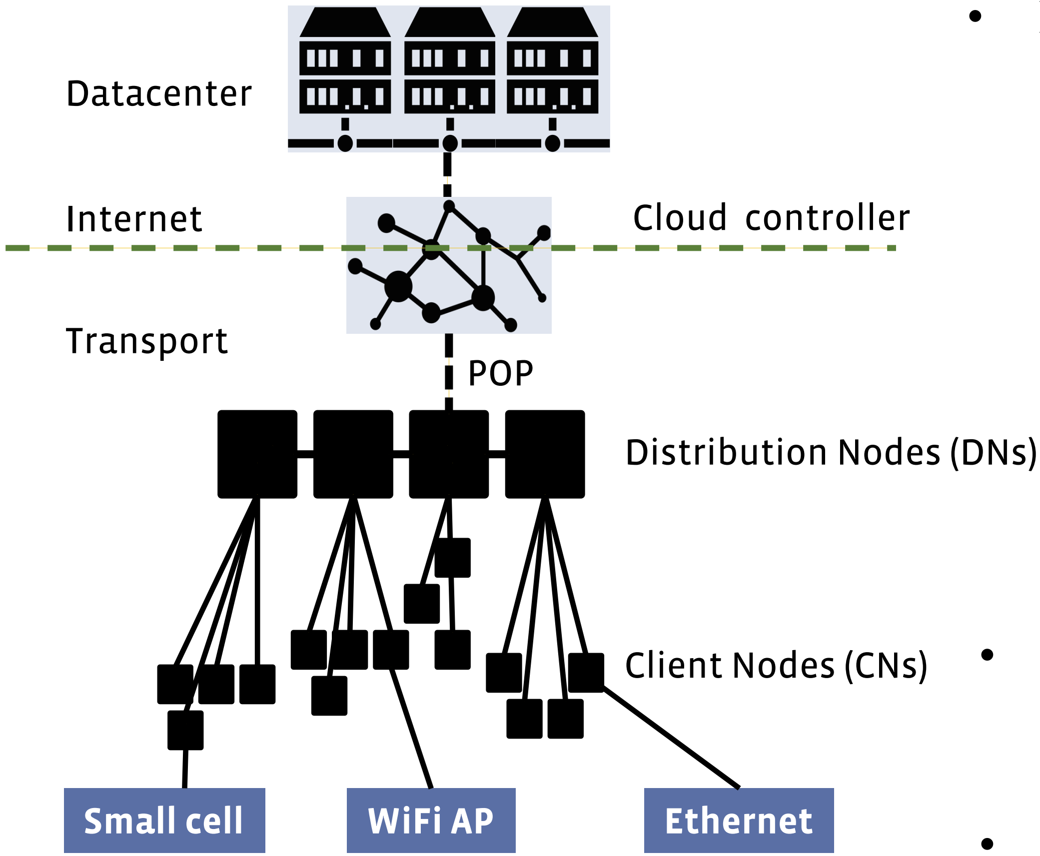
mmWave Distribution Network Use Cases [3]



mmWave Distribution Network

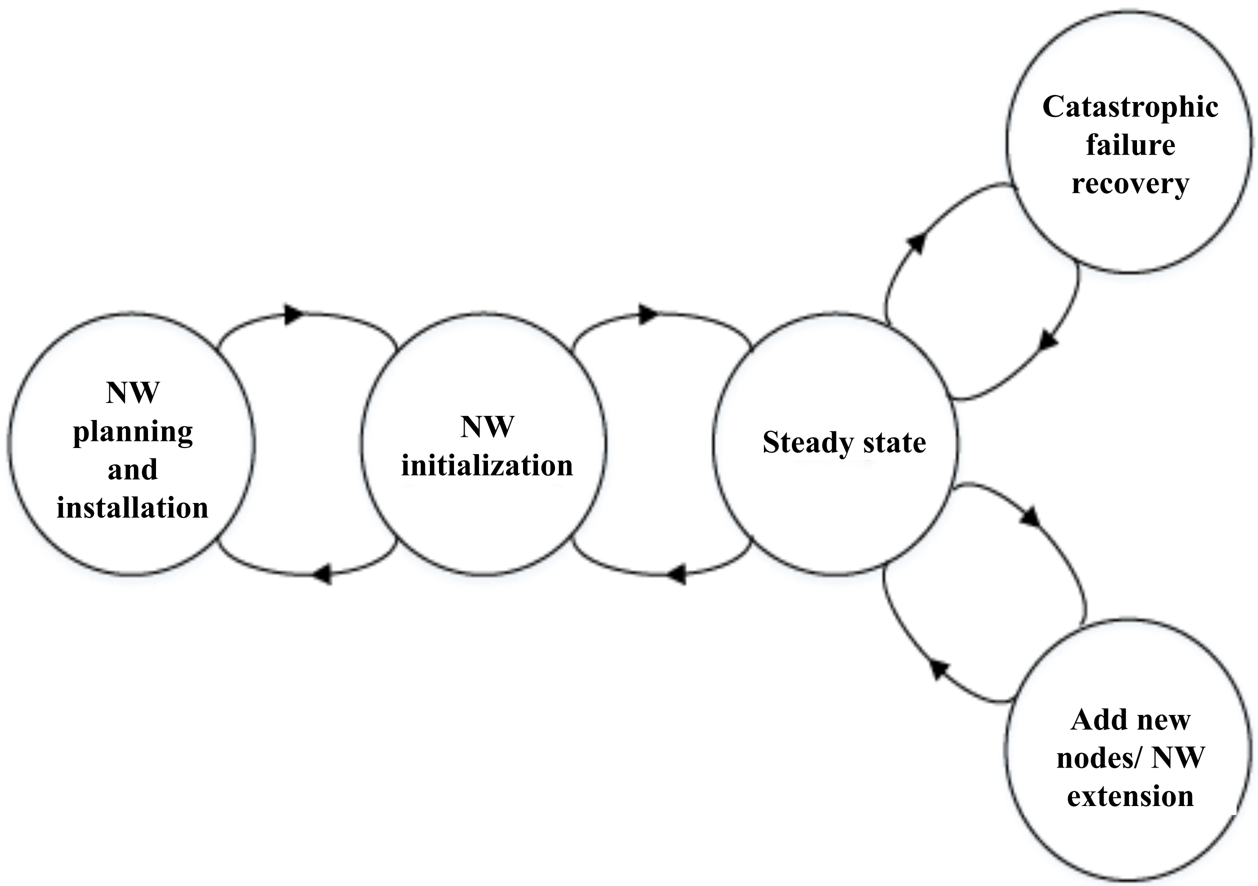
- LOS 60 GHz narrow beam system
- Own management and control per mmWave wireless access area
- Route control protocol supports re-routing over radio links
- Auto-alignment installations via adaptive beamforming
- Redundancy of active equipment at “first” pole next to fiber PoP or via connections to 2 or more fiber PoPs
- Radio link degradation and outage recognition w/ failure localisation

High Level NW Architecture

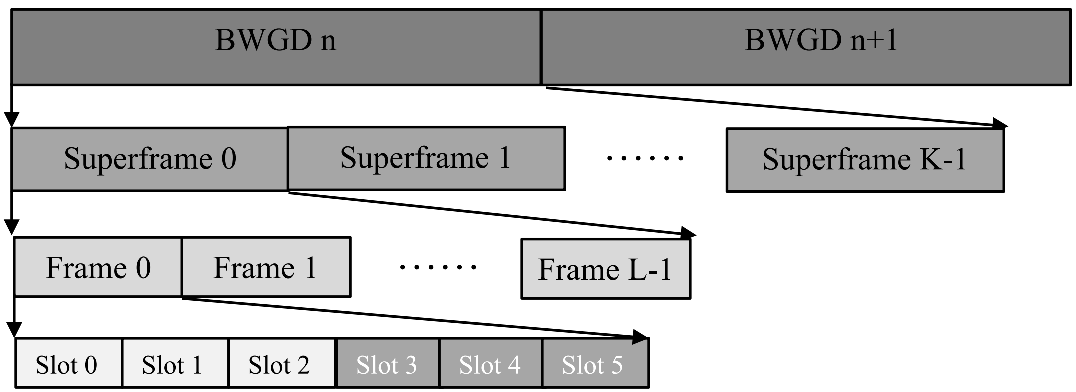


- **E2E Cloud controller**
  - Self-organizing aspect of NW operation
  - Improves service quality based on real-time analytics and anomaly detection
  - Optimal transport resource utilization to simplify network planning, deployment and operation
  - NW initialization, SW upgrades, interference management, traffic engineering/ SLA, congestion control, security, failure recovery, NMS, VN, etc
- **L2 features**
  - Developed on embedded processor based on PHY/MAC FW/Driver APIs
- **NPU user space**
  - E2E client, L3 routing and NMS agents

Main NW States With Impact to L2



Slot Structure in Steady State



Time Period	Typical Duration	Description
Slot	66us	Unidirectional (Tx or Rx), unequal length in general. Guard periods (4-8usec) in-between slots to ensure synchronization jitter and propagation delay don't degrade performance
Frame	400us	Consists of one Tx subframe and one Rx subframe. Typical 3 slots per subframe.
Superframe	1.6ms	Events across nodes in a network are synchronized to super-frame boundaries and numbers. Typical 4 frames per superframe.
BWGD	25.6ms	Bandwidth grant duration. Schedule (slot allocation bitmap) exchanged once every BWGD (retransmission upon failure). Typical 16 superframes per BWGD.

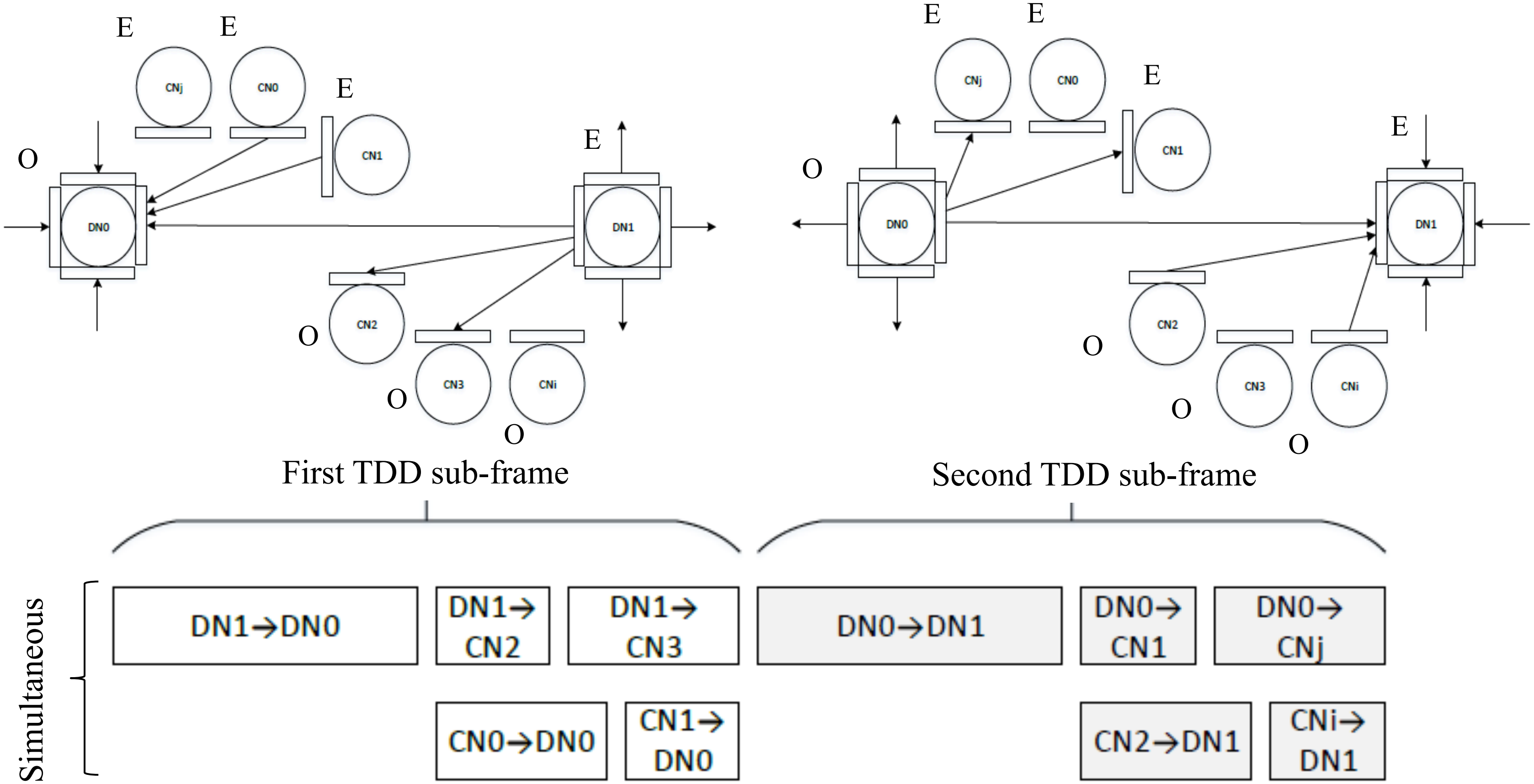
Data and Management plane

- **DN nodes synchronized via GPS for TDD sub-frame level timing alignment across the network (NW) [1]**
  - CNs track timing from serving DN
  - 1usec maximum drift any given time (TSF resolution)
- **Service Periods (SP) as slots for TDD/TDM access**
- **Data plane**
  - Standard 802.11ad/ay frames
  - (B)ACK delayed to next available slot in opposite direction
- **Management plane based on new set of IEs exchanged via action or announcement frames**
  - Custom payload to support new L1/L2 procedures

Keep-alive (KA) signaling

- **One or more IE's to provide support for:**
  - Bandwidth (BW) requests from CN to DN and DN to DN
  - Exchange of slot allocation bitmaps
  - Link quality measurement feedback (eg, SNR, PER, RSSI, etc) for MCS selection and Tx power control
  - Acknowledgement of KA frame reception in opposite direction
  - Optionally includes 802.11ad/ay time stamps for OTA timing synchronization of CNs
  - Typically periodic exchange (e.g., once per BWGD)

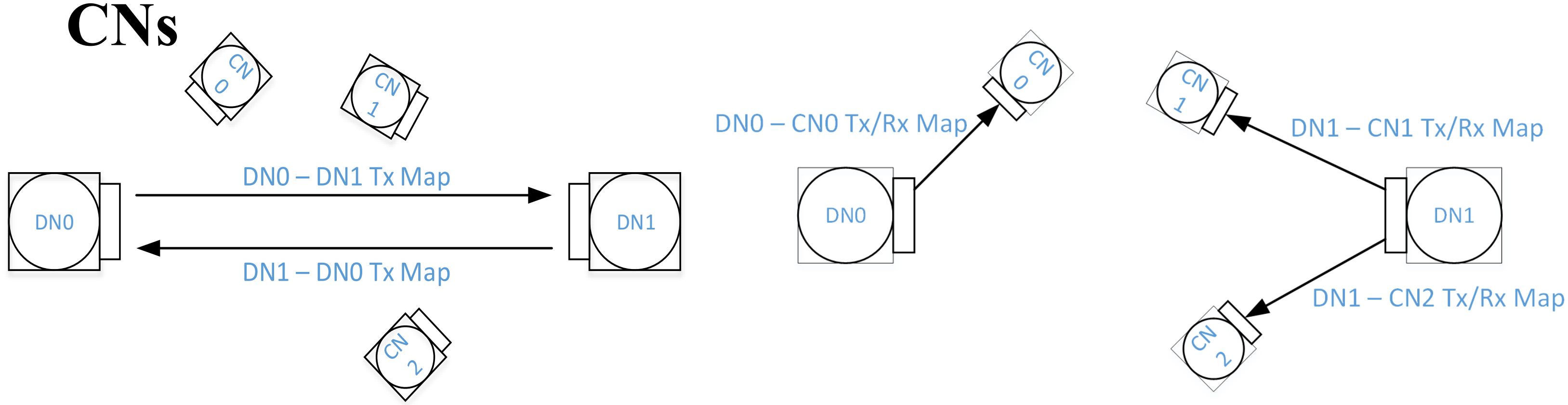
Odd and Even Node Polarity



- Even (E) nodes are transmiting (receiving) only in the first (second) TDD subframe
- Odd (O) nodes are receiving (transmitting) only in first (second) TDD subframe

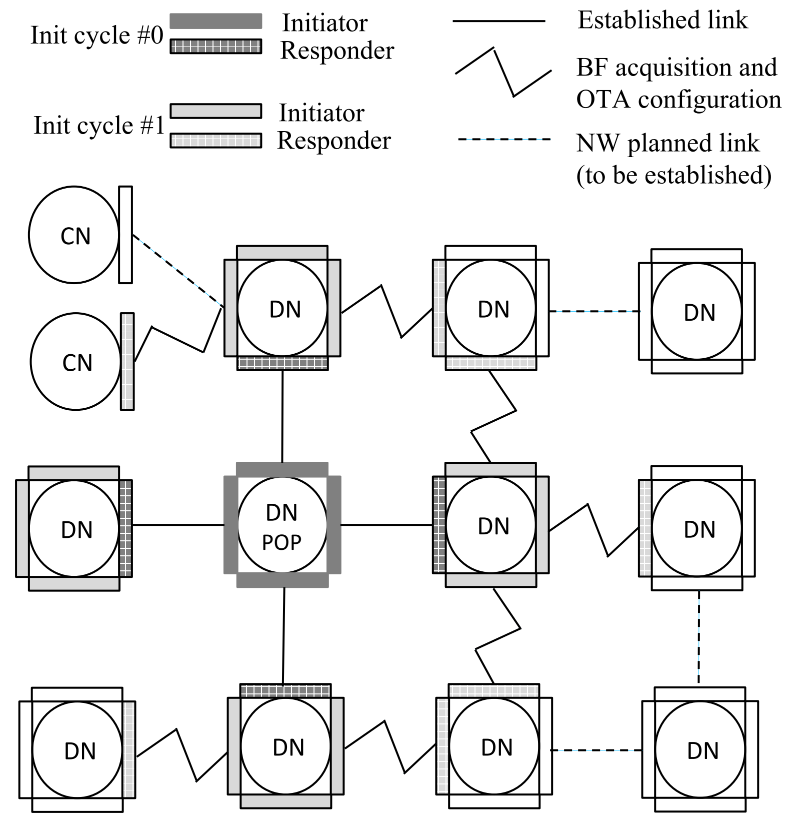
Dynamic L2 Scheduling Support

- **DN sectors exchange their Tx slot bitmaps with DN peer sectors (within KA messages)**
- **Each DN receives Uplink BW request messages from all associated CNs (e.g. once per BWGD)**
  - CN sends its Tx data rate (Mbps) and queue size (bytes)
- **Each DN sends Tx/Rx slot bitmaps to all associated CNs**



NW Initialization

- **Controller orchestrated multi-cycle process of establishing individual links in the pre-planned mesh topology**
  - Via BF acquisition followed by OTA node configuration
- **MAC address of each sector in mesh topology known to controller prior to initialization**
  - Bar-code on DN/CN sector box scanned before mounting and sent to controller database via out-of-band (installer app)



- Sectors of same DN are wired together and establish IP connection upon boot-up

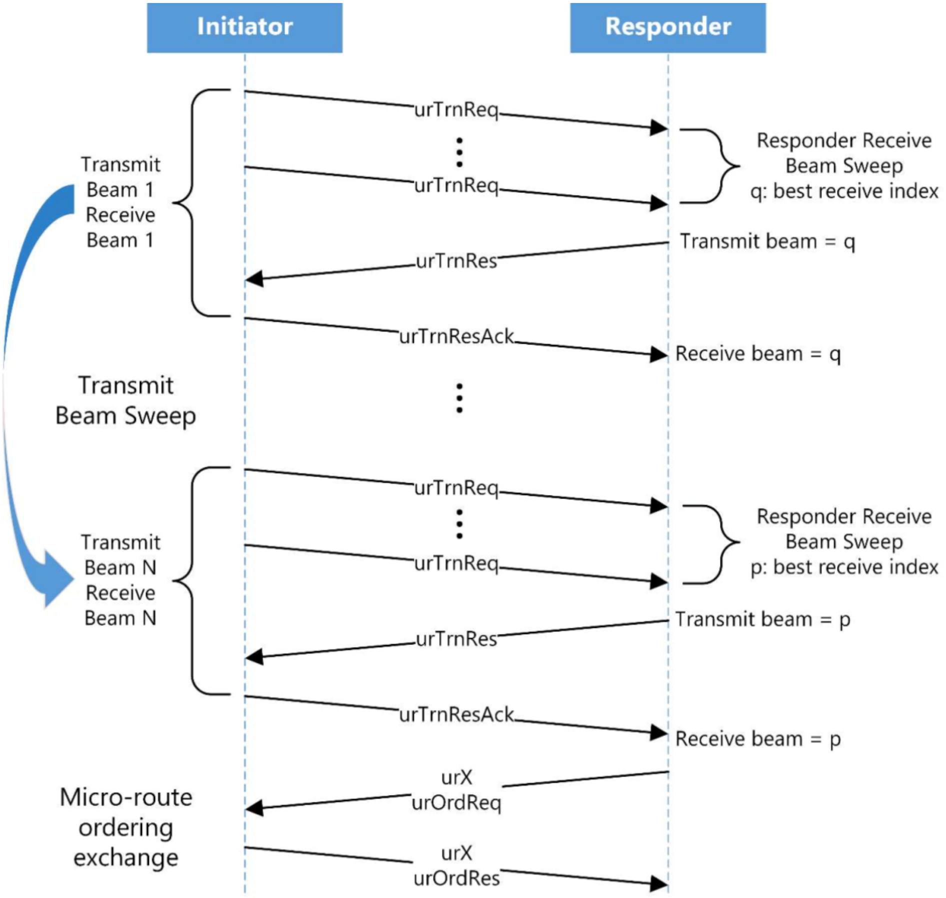
Link Establishment

- **Newly installed sector boots up in responder mode continuously sweeping beams in Rx mode**
  - Responder does not have information about configuration (e.g., slot structure, polarity assignment, Golay code assignment or DN/CN role)
- **In each initialization cycle, a sector with already established connection to controller is instructed to switch to initiator mode and start BF acquisition with targeted MAC address responder**
  - Initiator starts sweeping of Tx beams with BF training request (urTrnReq) and using default 802.11ad/ay Golay code
  - No blind discovery
  - No broadcast MAC transmission or promiscuous mode reception

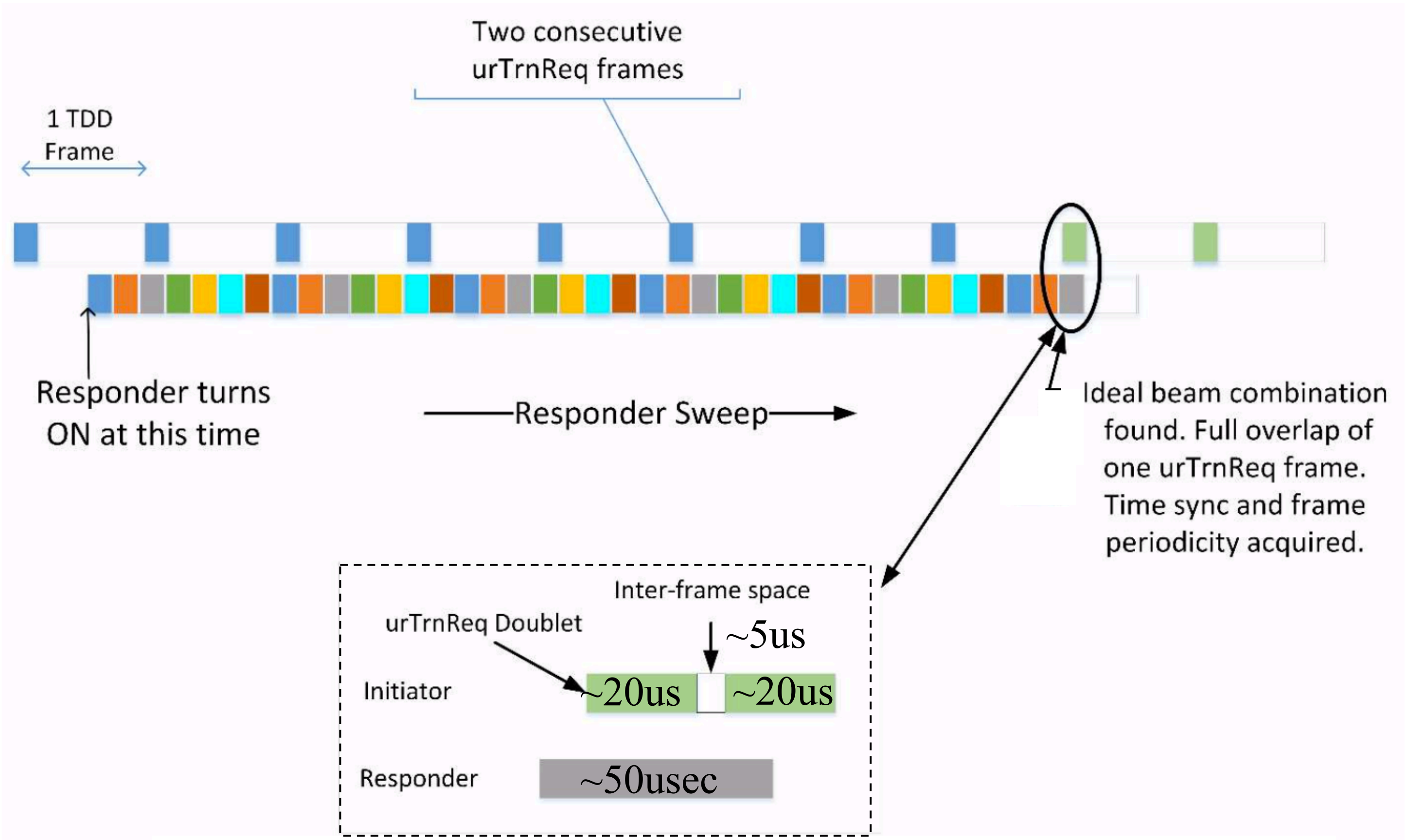
BF Acquisition Requirements

- **Directional beams on both sides of link**
  - Compensate for long distance, i.e., no quasi-omni antennas
  - Assume reciprocity on reverse link for initiator to receive BF training response (urTrnRes) from responder
- **Initiator could have active traffic with other nodes while instructed to initialize new DN/CN sector**
  - Add new nodes in point-to-multipoint (P2MP) configuration
- **CN's timing unsynchronized with rest of NW**
  - Start with asynchronous scan
  - Upon the first successful detection of BF training request by responder, switch to synchronous scan

BF Acquisition IE's exchange

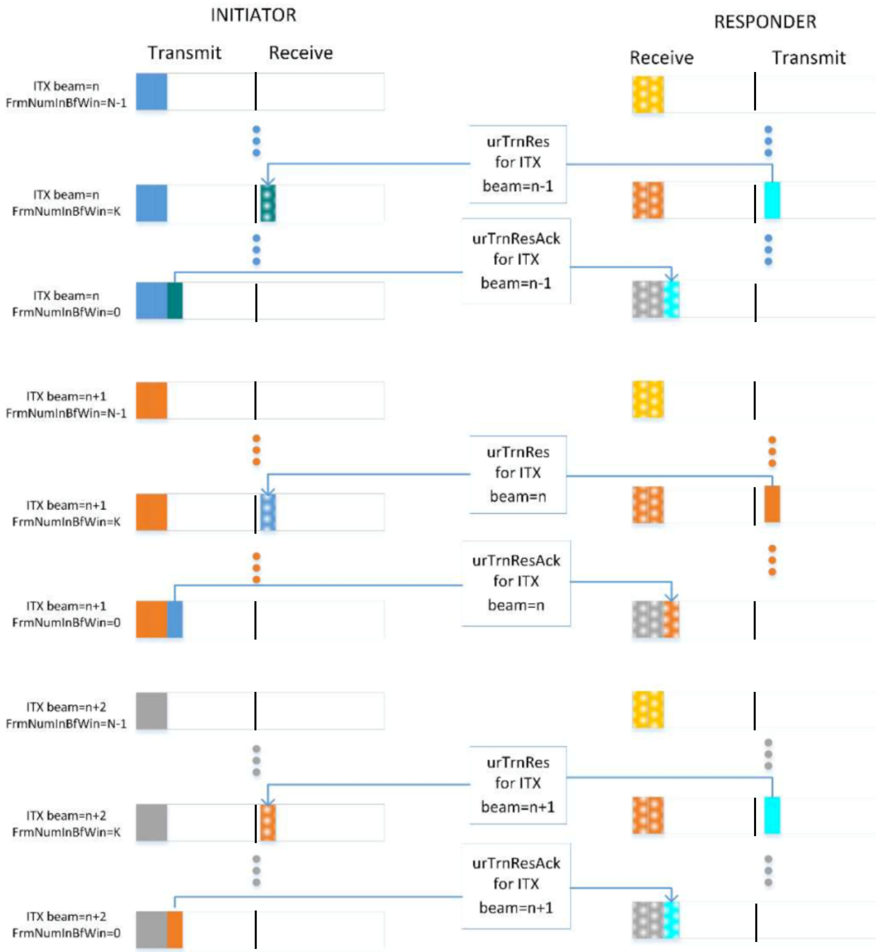


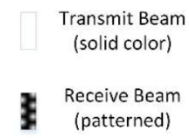
Asynchronous Scan Example



- Initiator uses only the first slot in each Tx sub-frame per its polarity assignment to transmit urTrnReq
- Allows to maintain traffic on existing links (P2MP) while initializing new ones

Synchronous Scan Example





- Initiator behavior does not change relative to asynchronous scan
- Responder synchronizes its Rx beam switching to overlap with initiator transmission in the first slot of its Rx TDD subframe
- This is not very important for BF acquisition stage (nothing to be saved in Rx slot occupancy) but it is crucial for periodic BF scan in steady state

Over the Air Configuration

- **Upon completion of synchronous sweep for all configured transmit beams, initiator sets the flag in urTrnReq to stop further training**
  - Responder and initiator subsequently exchange the best beam indexes to be used in each direction (urOrdReq and urOrdR exchange)
- **Before entering steady state where responder is ready to receive/ transmit user traffic, another 3-way handshake occurs to configure newly ignited sector with:**
  - Slot structure, security keys, polarity assignment, Golay code assignment and DN/CN role
  - This can be viewed as light Association/ Authentication
  - 3-way handshake uses also the first slot only

Periodic BF and Interference Scan

- **Periodic BF scan is equivalent to Sync BF Acquisition**
  - As a result of BF scan, each side of link can decide to unilaterally refine its Tx and/or Rx beams in vicinity of operating BF indexes (aka BF refinement)
  - Large BF index changes (aka BF switching) are coordinated to occur at the same super-frame boundary on both sides of link
- **Interference scan is largely equivalent to Synchronous BF Acquisition with few exceptions**
  - Initiator simultaneously trains multiple responders which are in steady state but not associated with given initiator
  - Training involves broadcast-MAC address
  - Each responder sends measurement results back to controller

Summary

- **This presentation introduced additional details to illustrate example L2 features important for mmW distribution network use cases concept [3]**
  - **TDD/TDM slot structure and dynamic L2 scheduling support**
  - **Beamforming (BF) acquisition for network (NW) initialization**
  - **Periodic Beamforming and Interference scan**
- **We are soliciting feedback to enhance these features and encourage technical contributions to help the standardization of newly introduced mmW distribution network use cases**

References

[1] IEEE 802.11-17/1022r0 “Changes to IEEE 802.11ay in support of mmW Distribution Network Use Cases” , Berlin (Germany), July 2017

[2] IEEE P802.11ayTM/D0.3, March 2017

[3] IEEE 802.11-17/1019r2 “mmWave Mesh Network Usage Model”, Berlin (Germany), July 2017

Appendix: List of Acronyms

BF	Beamforming
BW	Bandwidth
BWGD	Bandwidth Grant Duration
CN	Client Node
DN	Distribution Node
OTA	Over the air
KA	Keep Alive
NW	Network
PoP	Point of Presence
SP	Service Period
WTTB	Wireless to the Building
WTTH	Wireless to the Home

Appendix: Unequal Slot Length Example

- **Separate BA from Data and Management frames via dedicated BA slot**
  - Improves efficiency of slot packing for asymmetric UL/ DL traffic
  - Prevents stalling of Tx link when no corresponding Rx slot allocation for sending BACK available
  - Any received data frames immediately acknowledged in the next sub-frame
  - Prioritize Management + ACK over Data frames within slot
  - For Point-to-Point, combine everything into single slot to minimize guard period overhead

Slot 1	Slot 2	Slot 3
Management, ACK, Data	**Management, ACK, Data**	**BA**