IEEE802.15.3c Beamforming Overview

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Authors:

Name	Affiliations	Address	Phone	Email
I. Lakkis	Tensorcom	10875 Rancho Bernardo Rd, #108, San Diego, CA 92127	(858) 676-0200	ilakkis@ tensorcom.com
S. Kato	NICT	3-4 Hikarino-oka, Yokosuka, 239-0847 Japan		Shu.kato@ Nict.go.jp
C. Ngo	Samsung Electronics	75 W. Plumeria Dr., San Jose, CA 94132		Chiu.ngo@ samsung.com
J. P. K. Gilb	SiBEAM	555 N. Mathilda, #100, Sunnyvale, CA 94085		gilb@ieee.org

Abstract

- Antenna configuration independent multi-level BST (Beam Switching/Steering & Tracking)
- Supports any antenna(s) system, i.e. supports single antenna element, switched antennas, sectored antennas, 1-D and 2-D beamforming antenna arrays, etc.
- Superframe structure with directional beaconing, association, CAP, and CTAP

Beamforming Terminology

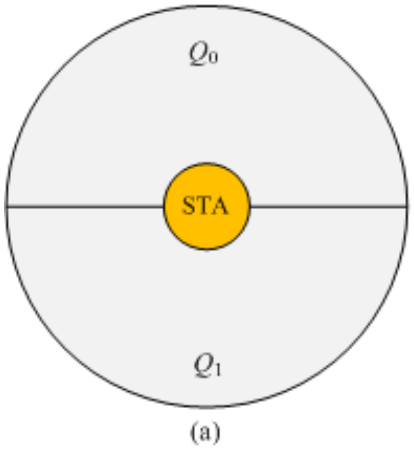
- **Quasi-omni patterns:**
  - 1st level resolution pattern
  - Refers to an antenna pattern that covers a very broad area of the Region of Space of Interest (RSI)
  - A STA covers the RSI with a minimal set of, possibly overlapping, Q-omni patterns
- **Sectors**
  - 2nd level resolution pattern
  - A pattern that covers a broad area of multiple beams that can be adjacent or not
  - Sectors can overlap

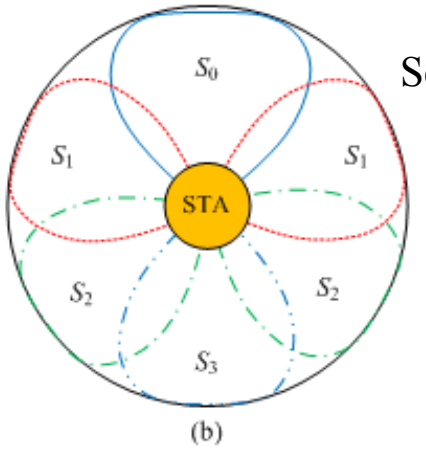
Beamforming Terminology

- **Beam**
  - 3rd level resolution pattern
  - Beams are a subset of High Resolution Beams (HRBs) or patterns
- **HR Beams**
  - Highest resolution level
  - Adjustment from Beams to HRBs is done during Tracking
- **Cluster**
  - A group of beams around a center beam
  - Clustering is used to facilitate tracking
  - Only the number of beams within a cluster is required

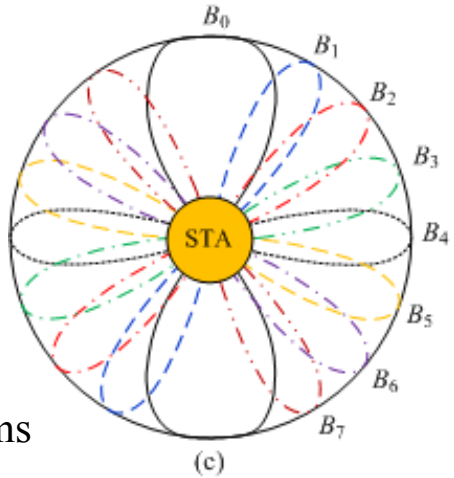
Beamforming Terminology

Q-omni Patterns

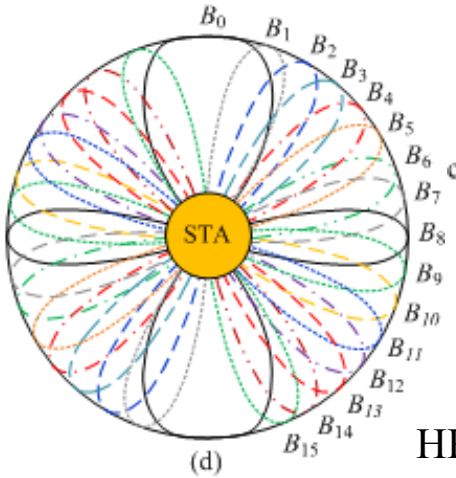




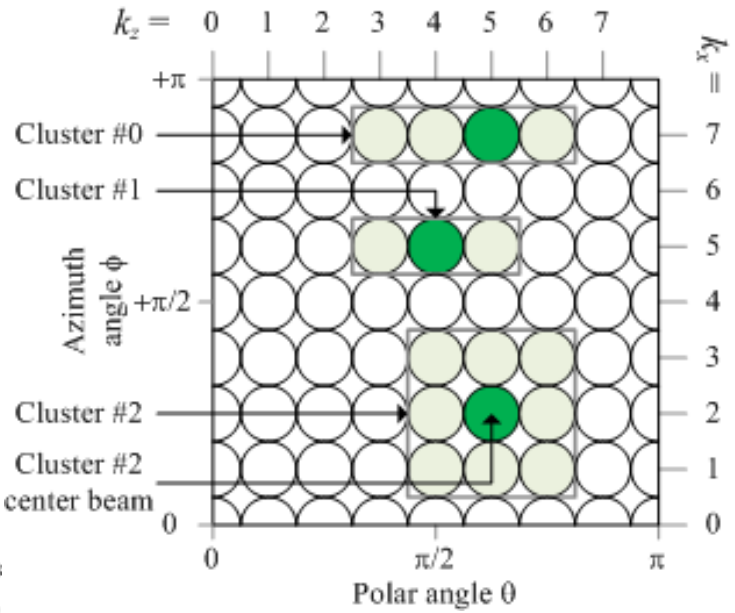
Sectors



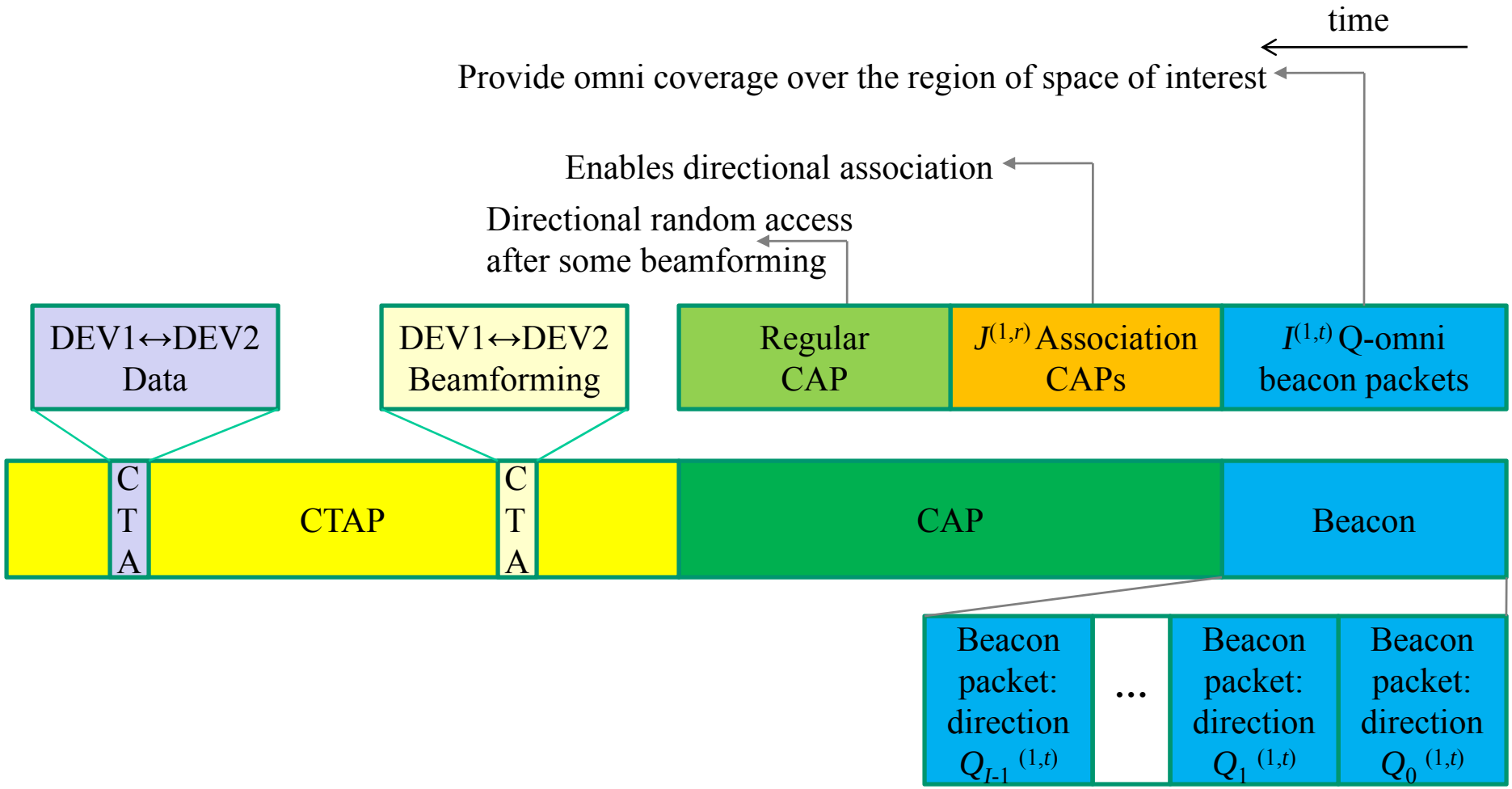
Beams



HR Beams



Superframe Structure

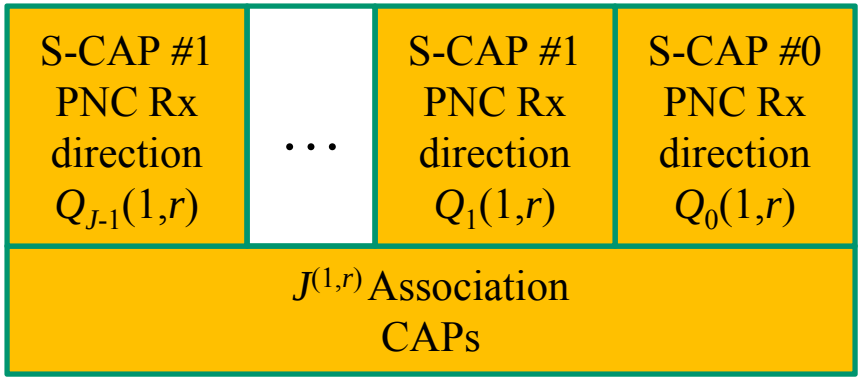


The Beacon

- PNC covers the region of space of interest by repeating /sweeping the beacon packet in $I^{(1,t)}$ Q-omni directions
- A STA may detect the beacon in one or multiple BIs (left to the implementer);
- The 1st beacon packet detected and demodulated by a DEV is not necessarily the best. DEV should measure the link quality from all other beacon packets to find the best PNC Tx direction and track it;
- After beacon detection, DEV has acquired knowledge of its best Rx Q-omni direction $q^{(2,r)}$ and PNC's best Tx sector direction $q^{(1,t)}$;

Association

- The association period is divided into $I^{(1,r)}$ sections corresponding to the PNC $I^{(1,r)}$ q-omni Rx directions;
- Using a time allocation for association enables a more efficient usage of the regular CAP;
- A DEV sends an "Association Request command" by sweeping over its $I^{(2,t)}$ Q-omni transmit directions;



Association

- The "Association Request" includes the information about the PNC best Tx Q-omni direction index toward the source DEV, i.e. $q^{(1,t)}$;
- If the channel between STA and PNC is reciprocal, sweeping is not necessary;
- STA uses its best Q-omni Rx direction(found during beacon detection) $q^{(2,r)}$ to listen for an "Association Response";
- Process is repeated in each association S-CAP until DEV successfully receives an "Association Response";

Association

- A successful association does not however mean that the PNC has acquired STA's best Tx direction. All we can say is that in the reverse link we have found a working DEV Tx direction;
- Fine tuning to find DEV's best Q-omni direction and higher resolution best direction should not be completed in A-CAPs to avoid polluting it;
- PNC should poll a DEV to a CTA (from time to time: left to the implementer) to perform at least the 1st level of beamforming which allows PNC and STA to track each other's best sector pair of directions

Regular CAP

- **Before two peer DEVs communicate in regular CAP, the two DEVs may perform beamforming;**
- **Configurable:**
  - Slotted Aloha
    - Enables spatial reuse
    - DEV↔ DEV or DEV↔ PNC
  - CSMA/CA for AV PHY
  - PNC based:
    - Directional RTS/CTS

Beamforming BST Protocol

- **The BST protocol is a very low complexity protocol:**
  - It is independent of antenna configuration, i.e. supports single antenna element, sectored antennas, switched antennas, beamforming antenna arrays of any nature;
  - Does not require any codebook exchange;
  - Requires a very little amount of information to be exchanged between STAs to operate properly, i.e. number of Tx & Rx directions;
- **The BST protocol is a bidirectional multi-level beamforming protocol, the outcome of which is:**
  - The best pair of directions in forward and reverse links and;
  - The start MCS to be used in each direction

Beamforming Protocol Summary

- **Sector level objective:**
  - Find fwd link (DEV1→DEV2) and reverse link (DEV2→DEV1) best pair of sector directions (in terms of LQI
  - Optionally second best pair of sector directions
  - Mapping of best pair of sector directions into a set of beam level directions in preparation for level-2;
- **Beam level objective:**
  - Find fwd link (DEV1→DEV2) and reverse link (DEV2→DEV1) best pair of beam directions
  - Mapping of best pair of beam directions into a set of higher resolution beam directions in preparation for nest level or tracking;
- **Tracking objective:**
  - Track the best pair of HR (high resolution beams) by monitoring the adjacent HR beams in the cluster centered around the best beam;
  - Switch to new better high resolution beam if found and re-cluster around the newly found HR beam

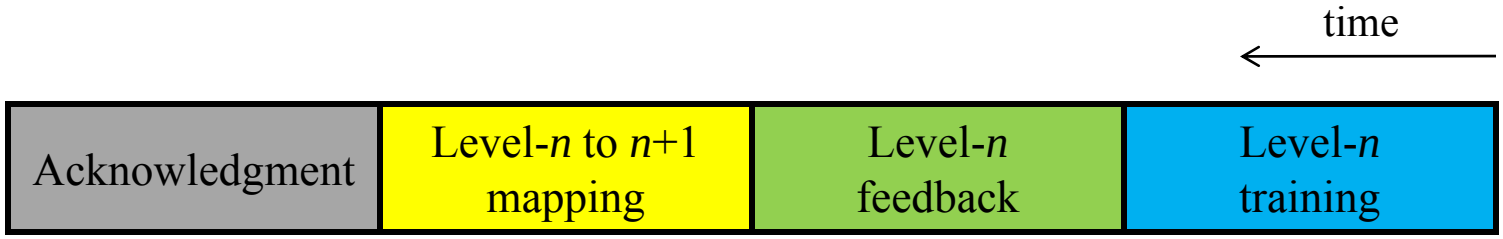
Beamforming

- **Beamforming between two DEVs or a DEV and PNC takes place in a CTA;**
- **DEV1 reserve a CTA from the PNC for the special purpose of beamforming with STA2**
- **The BST beamforming protocol consists of a two-level beamforming, followed by a tracking phase:**
  - Two-level beamforming:
    - Sector level
    - Beam level
  - High resolution beam level (tracking)

Beamforming CTA Reservation

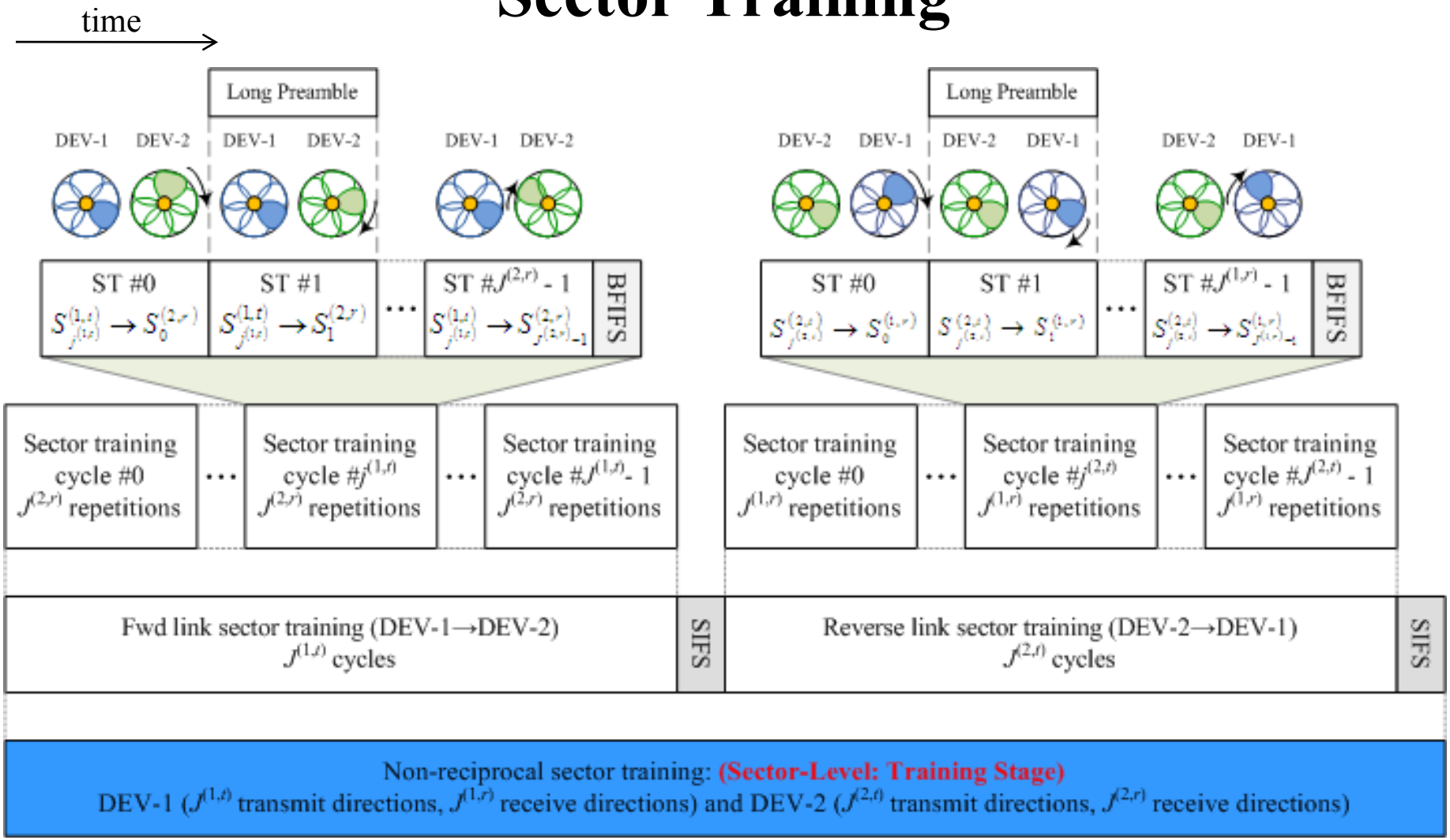
- **Beamforming between two DEVs or a DEV and PNC takes place in a CTA;**
- **DEV1 reserve a CTA from the PNC for the special purpose of beamforming with STA2;**
- **PNC allocates a CTA & broadcasts the CTA allocation, DEV1's and DEV2's "Beamforming capabilities"**
- **DEV1 and DEV2 start the beamforming process in the allocated CTA;**
- **DEV beamforming capabilities:**
  - #Tx sectors = 1 ⇔ DEV is Tx omni-capable in (RoSoI)
  - #Rx sectors = 1 ⇔ DEV is Rx omni-capable in (RoSoI)
  - #Antenna Type (0 ⇔ no beamforming, etc.)

Sector & Beam Level Format

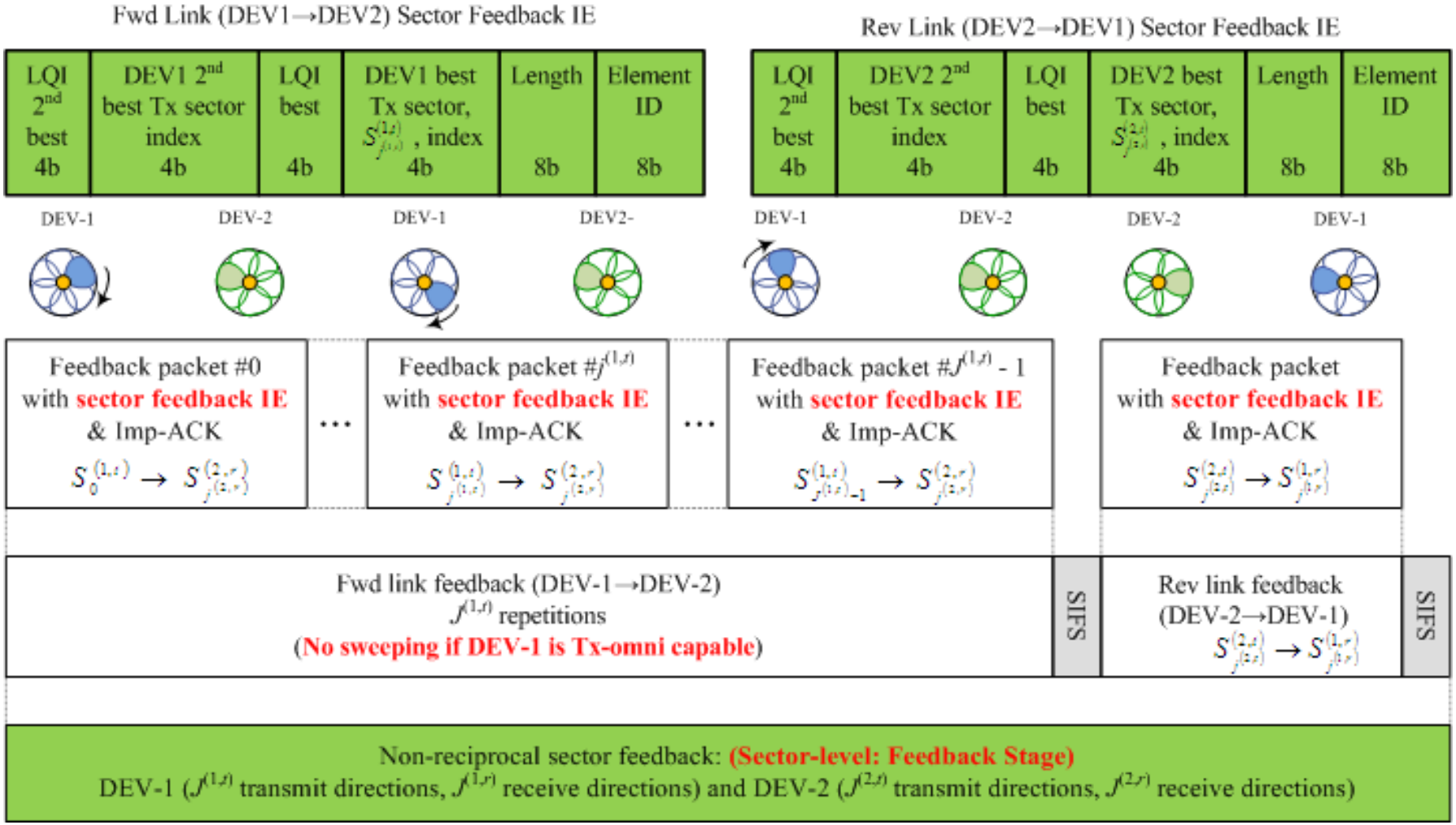


- **Unified sector and beam level format (n=1, 2, 3)**
  - *Level-n training*: forward and reverse link sweeping
  - *Level-n feedback*: feedback of best and 2nd best directions and associated LQIs;
  - *Level-n mapping*: mapping of best direction results of current level into a set of directions to be used in level *n*+1 (3 being tracking);
  - *Acknowledgment*: closes the loop

Sector Training



Sector Feedback



Sector-Level Mapping

- **Sector → Beam mapping IE**
  - Number of DEV Tx beams
  - Number of DEV Rx beams

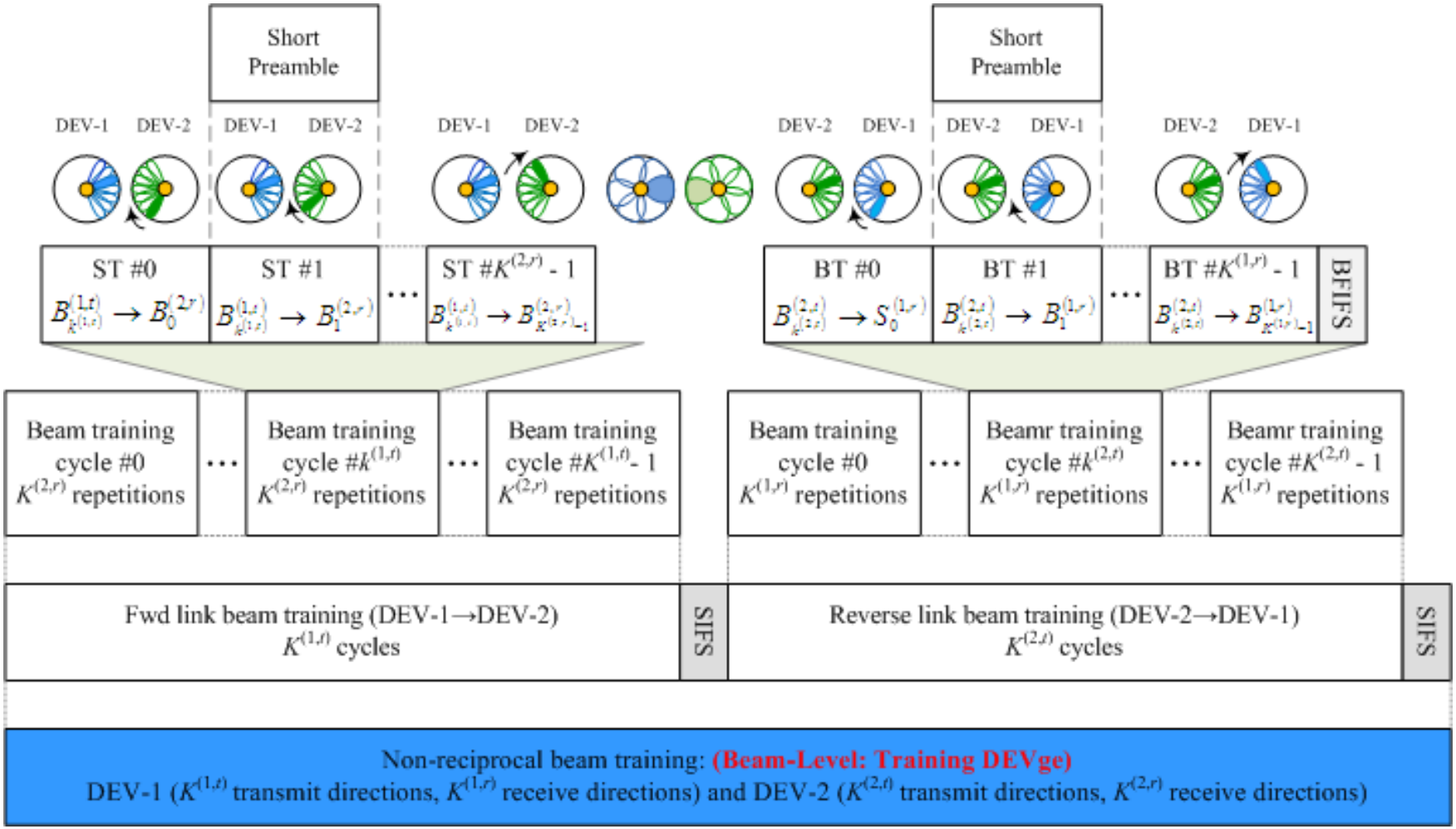
DEV2→DEV1 : Sector Mapping IE

RES	Number of DEV2 Rx beams - 1	HR Beam SYNC Mode	Number of DEV2 Tx beams - 1	Length	Element ID
2b	6b	2b	6b	8b	8b

DEV1→DEV2 : Sector Mapping IE

RES	Number of DEV1 Rx beams - 1	HR Beam SYNC Mode	Number of DEV1 Tx beams - 1	Length	Element ID
2b	6b	2b	6b	8b	8b

Beam-Level Training



Beam-Level Feedback

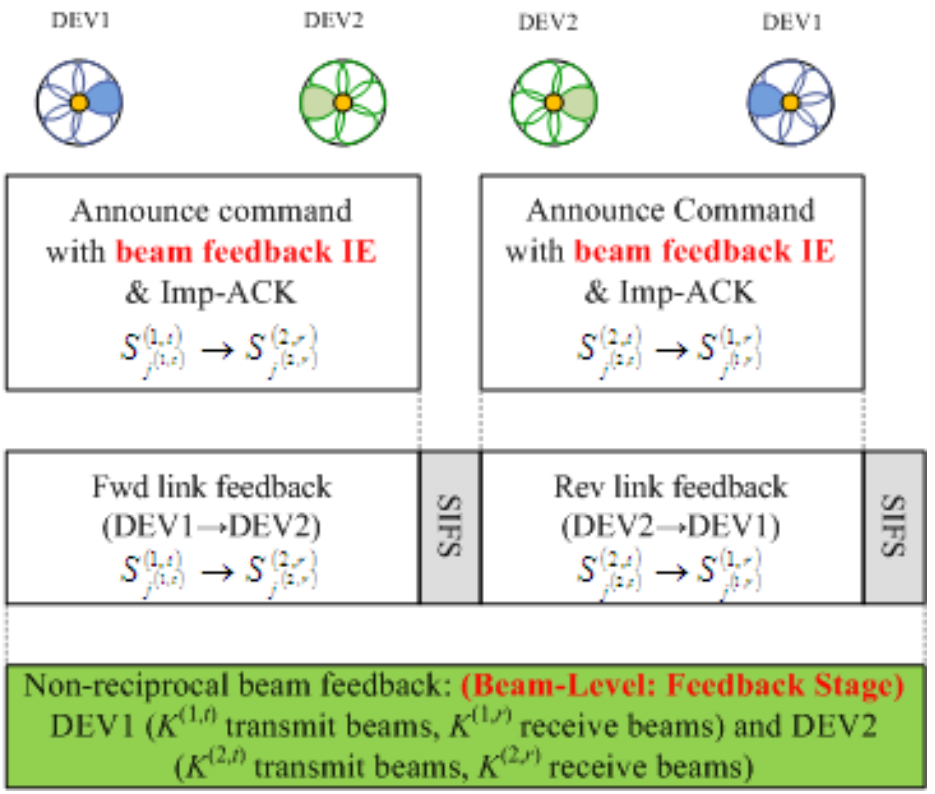
- **Feedback Stage:**
  - Fwd link DEV1→DEV2: uses best pair of sectors from 1st level
  - Fwd link DEV2→DEV1 uses best pair of sectors from 1st level

Fwd Link (DEV1→DEV2) Beam Feedback IE

LQI 2nd best 4b	DEV1 2nd best Tx beam index 4b	LQI best 4b	DEV1 best Tx beam, $B^{(1,t)}_{k^{(1,t)}}$, index 4b	Length 8b	Element ID 8b

Rev Link (DEV2→DEV1) Beam Feedback IE

LQI 2nd best 4b	DEV2 2nd best Tx beam index 4b	LQI best 4b	DEV2 best Tx beam, $B^{(2,t)}_{k^{(2,t)}}$, index 4b	Length 8b	Element ID 8b



Beam-Level Mapping

- **Beam → HR-Beam mapping IE**
  - Number of DEV Tx HR (High Resolution) beams
  - Number of DEV Rx HR (High Resolution) beams

DEV2→DEV1 : Beam Mapping IE

RES	Number of DEV2 Rx HR beams - 1	HR Beam SYNC Mode	Number of DEV2 Tx HR beams - 1	Length	Element ID
2b	6b	2b	6b	8b	8b

DEV1→DEV2 : Beam Mapping IE

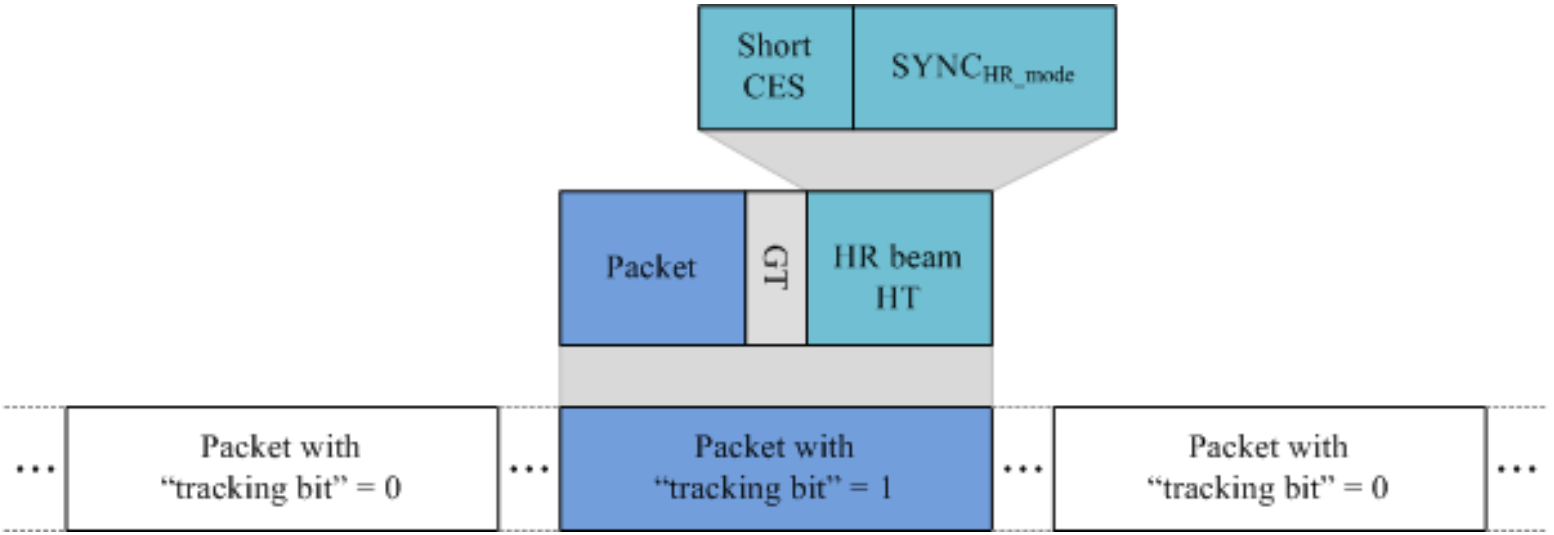
RES	Number of DEV1 Rx HR beams - 1	HR Beam SYNC Mode	Number of DEV1 Tx HR beams - 1	Length	Element ID
2b	6b	2b	6b	8b	8b

Tracking

- **Clustering Rules:**
  - Definition: a set of adjacent beams identified by a center beam
  - Clusters are paired, i.e. a cluster-1 from DEV1 is associated to a cluster-1 from DEV2 & cluster-2 from DEV1 is paired with cluster-2 from DEV2
- **Tracking mechanism:**
  - Track center beam in each cluster (re-clustering)
  - Tracking packets are used to enable distributed tracking
  - A tracking packet is a regular packet with “Tracking Bit Field” set to 1 in the PHY header, and followed by beam training sequence (short preamble)

Tracking

- **A Packet with "Tracking Bit" set to one is followed by a short training sequence transmitted in on of the HR beam directions within the cluster;**



Summary

- BST is one of two beamforming protocols adopted in IEEE802.15.3c;
- BST is simple and require only exchange of number of directions within a given stage;
- BST is independent of the used antenna system;
- BST is based on a two-level beamforming: a sector level and a beam level
- Tracking moving DEVs is enables by the distributed cluster of HR beams tracking

References

- 15-08-0055-00-003c-Beamforming
- 15-08-0182-00-003c-Multi-Resolution-Beamforming
- 15-08-0361-00-003c-Beamforming
- 15-08-0355-00-003c-Beamforming-Draft