Constraint-Based Routing for End-to-End MMR Cell Connection Management

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Purpose:

Technical contribution for MMR MAC layer functions on end-to-end connection management

Highlights

This presentation has consolidated and harmonized many submitted contributions from Session #46 discussions which cover:

- **Relay path interfaces associated with various routing schema (centralized vs. distributed)**
- **Routing management including path identification, path creation/maintenance and path population**
- **Constraint-based routing for end-to-end connection management**
- **Various type of connections, relay CID semantic and their relationship with the routing paths and interfaces**
- **CID/Path biding operation and related signaling mechanism**
- **Data forwarding schema associated with various connections**
- **QoS granularities associated with various connections**
- **Security issue related to path-oriented operations**

This presentation systematically discusses the relay interfaces and procedures on how to manage end-to-end relay connections in MMR network. The purpose of this presentation is to build up a common framework for MMR MAC layer to manage connections, to promote more discussions and to pursue more harmonization from different contributors

Key Operations – Relay Path

(from Session #46 contributions)

- **End-to-End Relay path is between MR-BS and a designated access RS (802.16j-06/014) (Note: path here was defined as topological object, not connectivity object)**
- **Who create a path?**
  - **A path is created by radio resource routing controllers which are either in MR-BS (centralized routing domain), or MR-BS and the cluster head RS (distributed routing domain)**
  - **Thus a relay path might be concatenated by sub-path, depending on how sub-path is managed in each domain (e.g., cluster-based routing).**
- **Who need a path?**
  - **MR-BS only (centralized routing), or MR-BS and RS (distributed routing)**
  - **A path is needed to guide the payload burst and mgmt data forwarding and to curb the broadcast traffic downstream**
  - **A path can exist without any MS attached**
- **When is a path created?**
  - **When a RS joints a MR-cell via network entry, or re-joint a MR-cell via handover**
  - **A path is determined by MR-BS or cluster RS after the newly joint RS finished the entry process**
- **How a path is populated?**
  - **In distributed routing, a path is populated to the RS by MR-BS or by cluster RS via the group-cast signaling messages**
- **What are path-associated operations over the air interface?**
  - **Path creation/change/deletion/maintenance**
  - **Path population**

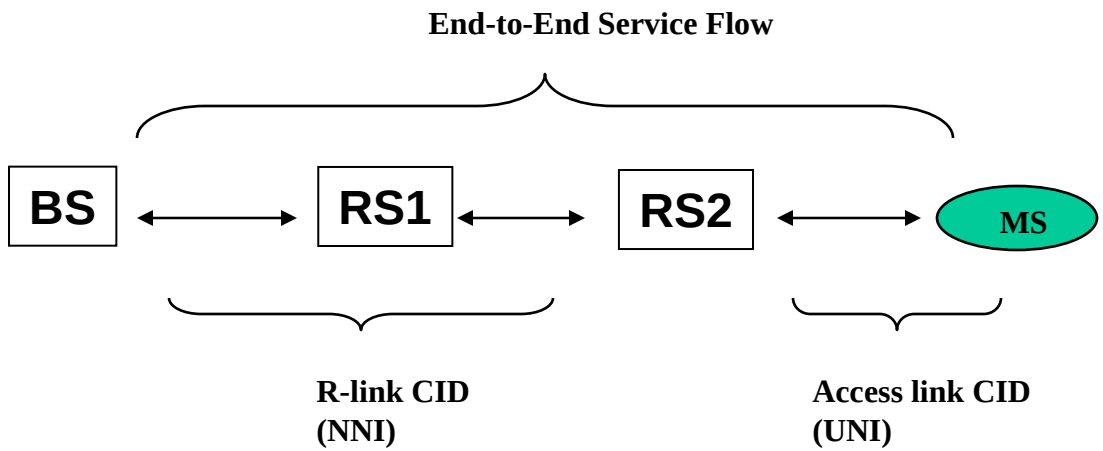
Key Operations – Relay Connection

(from Session #46 contributions)

- **MMR is a multi-tier PMP network, with p-to-mp schema downstream and p-to-p schema upstream**
- **Downstream intermediate RS needs CID/Path binding to navigate data forwarding and to curb the broadcasting**
- **Downstream/Upstream intermediate RS uses CID for traffic aggregation and QoS purpose**
- **Various type of connections**
  - **Macro pipe: end-to-end tunnel for global connections (both downstream and upstream)**
  - **Micro pipe: link-by-link connection with/without local CID concatenation (e.g., CID swapping)**
  - **Hybrid: combination of macro pipe and micro pipe (e.g., Macro pipe between BS and access RS, micro pipe between access RS and MS)**
- **How a path is associated with connections ?**
  - **Control-plane-connection and data-plane-connection are associated with a given path**
  - **Signaling messages (e.g., DSx), or some new messages, can be used to populate CID/PATH binding**
- **Group-cast signaling vs. Uni-cast signaling**
  - **Group-cast signaling is used to populate binding info (Macro or Micro) to every RS along a given path**
  - **Uni-cast signaling is used only to a designed access RS (e.g., MS's CID)**
- **Connection and QoS**
  - **Per-Macro-flow QoS: QoS-classified tunnels for aggregated traffic**
  - **Per-micro-flow QoS: SF-based QoS link-by-link**
  - **Per-packet QoS: Diffserv-like QoS, with QoS-bit defined in MAC PDU header (sub-header)**
  - **QoS population: per-relay-link vs. access-link-only**
- **Data burst forwarding along the relay paths**
  - **Per-connection-based: Transport CID is used in MAC subheader**
  - **Per-packet-based: RS-ID or basic-CID is used in MAC subheader as destination**

MMR Connectivity: R-link vs. Access Link

- **Decouple R-Link operation from Access link operation**
  - Two interfaces: relay link NNI (Node-to-Node-Interface between RS) and access link UNI (User-Network-Interface between RS and MS)
  - Relay path signaling is triggered only for R-link operation
  - Access link signaling (IEEE 802.16e-2005) between BS and MS is transparent to all R-link
- **Service flow over end-to-end connectivity**
  - Service Flow (SF) info only stored in BS and MS (IEEE 802.16e-2005)
  - SF traffic is piggy-backed by relay connectivity and access connectivity end-to-end
- **CID semantic**
  - R-link CID represents a virtual path connection (a.k.a., VPI)
  - Access CID represents a virtual circuit connection (a.k.a., VCI)



MR-cell Constraint-Based Routing

- **Constraint-Based Routing:** The process of determining the most suitable routes in a MR-cell subject to constraints of available radio resource over the route.
- **Explicit Route:** In constraint-based routing, the path is determined by MR-BS or cluster RS, and the path is specified as explicit route in the signaling messages (distributed routing schema), or in the source-routing case (centralized routing schema), the explicit route to be embedded in data burst for navigating the relay.
- **Route presentation**: A route is represented by an array of node ID (e.g., RS-ID, or cell ID)
- **Path ID:** A path-ID can be assigned to an explicit route for end-to-end operation.
- **Path operation:** A Relay path can be created/maintained/populated by utilizing DSx signaling messages (IEEE 802.16e-2005), or some newly defined messages, with the extension of explicit route.
- **Connection/Path binding**: Control-plane connections and data-plane connections can be bound (via signaling) to a particular path in the routing table.
- **Redundant Path**: Multiple paths may be assigned to the same destination

New TLV for Path Objects

- Explicit route

Syntax	Size	Notes
N_entry	8 bits	The number of entries in the list
For(j=0;j<N-entry;j++) {		
RS_ID	8 bits	RS_ID represents a relay node along a given path
}		

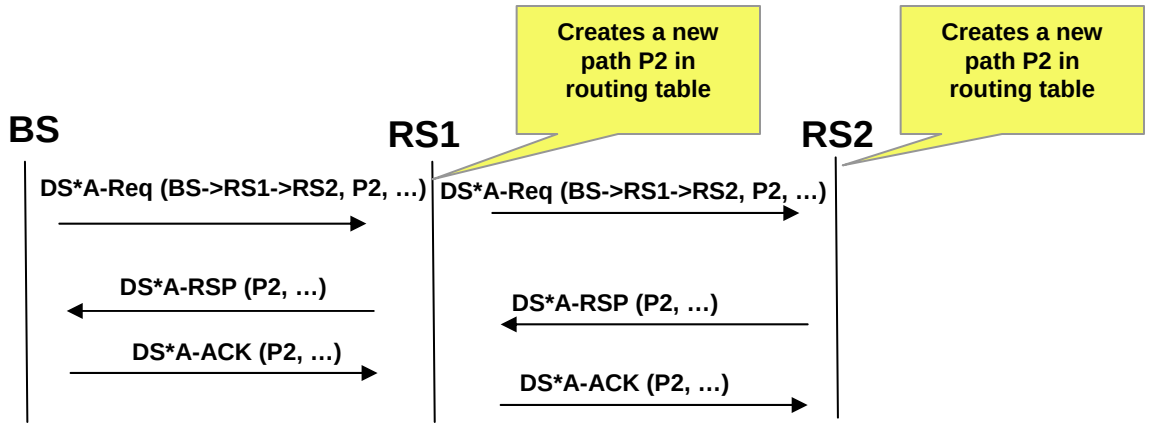
- Path ID

Syntax	Size	Notes
Path_ID	32 bits	The first 24-bit is the Node-ID and the rest 8-bit is the local integer assigned to a path

To guarantee the path uniqueness within a distributed scheduling environment, Node_ID prefix may be needed,

Path Creation and Population

- **After RS2 finished the entry process, BS would determine a path (BS->RS1->RS2) with path ID P2**
  - BS sent DSA(BS-RS1-RS2, P2, …) to downstream. DSA contains RS2's basic CID as destination, and the allocated transport CID for RS2
  - For the received DSA message, RS1 would check the Explicit route. If it does not find a match, RS1 simply drops the message
  - If RS1 is in the list, and this is a new path P2, RS1 would store Explicit route, path ID P2, the basic CID and the allocated transport CID into routing table.
  - Note that in distributed routing domain, if the transport CID only has the local sense, RS1 might allocate a new transport CID for RS2, and set up a mapping relationship between these two transport CID.
  - RS1 further sends DSA downstream with the same transport CID, or newly allocated transport CID.
  - For the received DSA, RS2 determined its self was the destination, and stored Explicit route, path ID P2, and the allocated transport CID into routing table.
  - Now an end-to-end relay connectivity (from BS to RS2) could be represented either by a single transport CID (centralized routing), or by the concatenation of several transport CID (distributed routing).
  - This end-to-end connectivity is constrained by the given path
  - Thereafter, all operations against the given path could use path ID (e.g., path maintenance, creating new connectivity over the same path, etc.,).

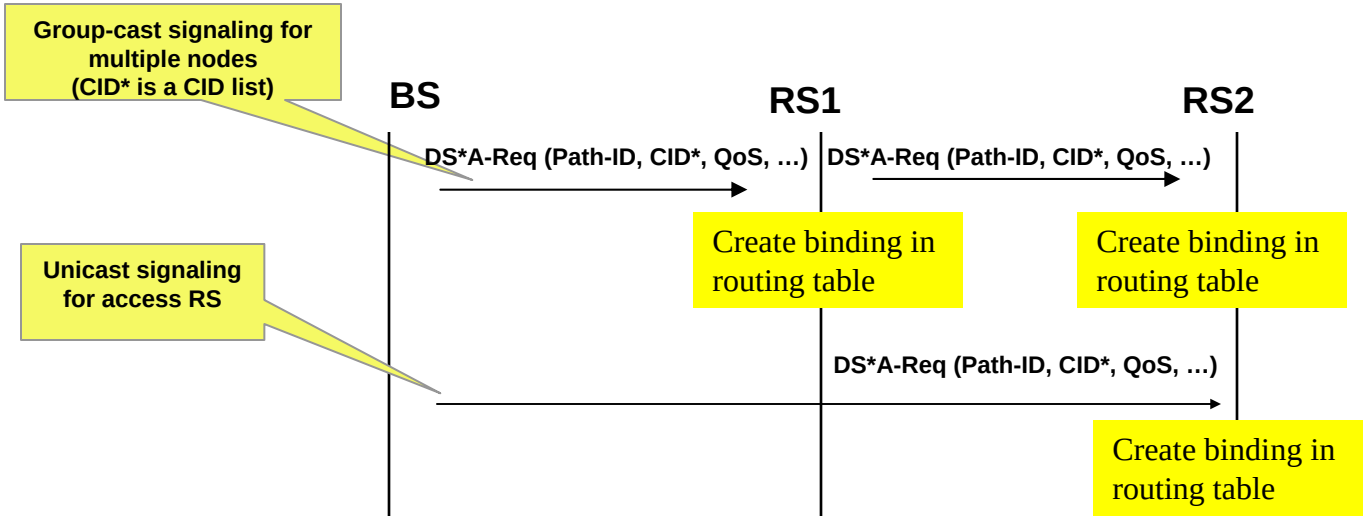


Connection Management

- **CID Assignment**
  - CID is allocated/managed by Radio resource scheduler (centralized or distributed)
  - CID semantic is aligned with IEEE 802.16e-2005, and associated with various connectivity
  - For example, when a transport CID is used for end-to-end tunnel purpose, it is a “tunnel CID”; otherwise it represents a local link connection
- **CID binding with routing path**
  - CIDs are coupled/decoupled to/from routing path to create/release end-to-end connectivity
  - This mapping is done via signaling messages with explicit route or path ID
  - The mapping relationship is established and stored in routing table and data forwarding table
  - End-to-end connection can be represented by a global “tunnel CID”, or by the concatenation of a set of local CIDs
  - For example, a designated access RS’s Basic CID (or a transport CID) can be used as unicast tunnel CID in forwarding table to guide the burst relay while this CID is used in DL-MAP_IE (IEEE 802.16e-2005)
  - Alternatively, CID swapping (between ingress link CID and egress link CID) can be used to create an end-to-end relay connection
- **Bandwidth management with routing path**
  - Bandwidth request/grant is associated with end-to-end relay connectivity
  - Radio scheduler allocated bandwidth based on global traffic demand & global link conditions
  - Global (or distributed with coordination) scheduling can guarantee fairness, traffic balancing, and avoid contention over relay links

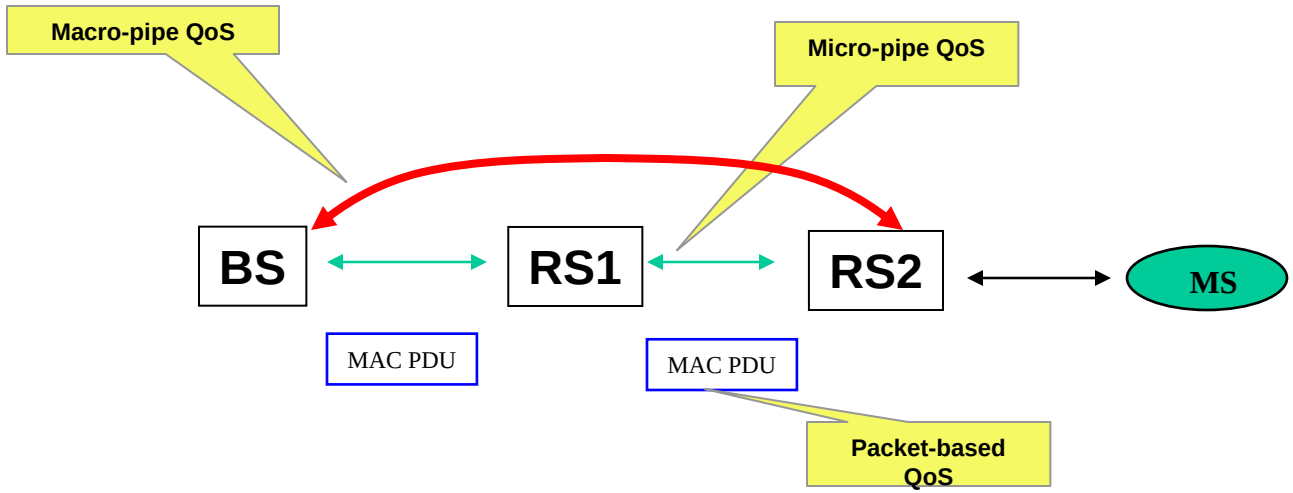
CID/PATH Binding

- **CID/PATH binding for Marco-pipe or Micro-pipe**
  - Macro-pipe binding is triggered by BS during tunnel provisioning
  - Micro-pipe binding is triggered by BS or MS during service flow provisioning (802.16-2005)
- **End-to-end signaling to populate binding relationship and QoS**
  - Path-ID for explicit route
  - QoS profile associated with CID (optional)
  - Group-cast signaling for populating Macro pipe and Micro pipe to every RS along the path
  - Unicast signaling for populating MS's CID (and QoS) to access RS only



QoS: Granularity vs. Complexity

- **Marco-pipe QoS** (high scalability)
  - Macro-pipe QoS is connection-based, but with QoS profile pre-provisioned to each tunnel (R-link CID)
  - Per-tunnel QoS profile is populated to each RS via group-cast signaling
  - Tunnel end points (BS and access RS) map MS-CID into tunnel CID
  - Based on received tunnel CID, each relay RS puts data-burst/MAC PDU into various QoS queue
- **Micro-pipe QoS** (low scalability)
  - Micro-pipe QoS is connection-based, but with QoS profile provisioned to each MS-CID
  - Per-flow QoS profile is populated to each RS via group-cast signaling
  - Every RS handles QoS based on received MS-CID
- **Packet-based QoS** (high scalability)
  - QoS bits are carried in each MAC PDU header/sub-header
  - Tunnel end points (BS and access RS) map MS-CID into tunnel CID with QoS bits
  - Based on received QoS bits, each relay RS puts data-burst/MAC PDU into various QoS queue



Data Burst Forwarding (1) – Per-Connection Based

- **Per access link CID forwarding end-to-end over R-link**
  - Access link transport CID (i.e., MS CID) is populated to every RS along the path (via path/CID binding)
  - For the received MPDU, RS determines if it should be further forwarded or dropped
  - Upstream traffic is relayed to BS as 802.16-2005
- **Per R-link CID Tunneling end-to-end over R-link**
  - Access RS's transport CID is populated to every RS along the path (via path/CID binding)
  - Destination RS's transport CID is carried in R-MAP_IE, or in a aggregated MPDU header
  - The related burst only contains all MAC MPDUs either targeting to the designated RS (e.g., mgmt messages), or targeting to the all MSs attached to this RS
  - For the received burst/MPDU, RS determines if it should be further forwarded or dropped
  - Upstream traffic may be aggregated with R-link CID in MPDU header at access RS, and is relayed to BS as 802.16-2005
- **CID Swapping**
  - Per-link swapping: per-MAC PDU processing, or per-burst processing at every link with locally defined CIDs
  - Per-cluster swapping: CID is only swapped at the boundary of clusters, (i.e., CID is global within a cluster).

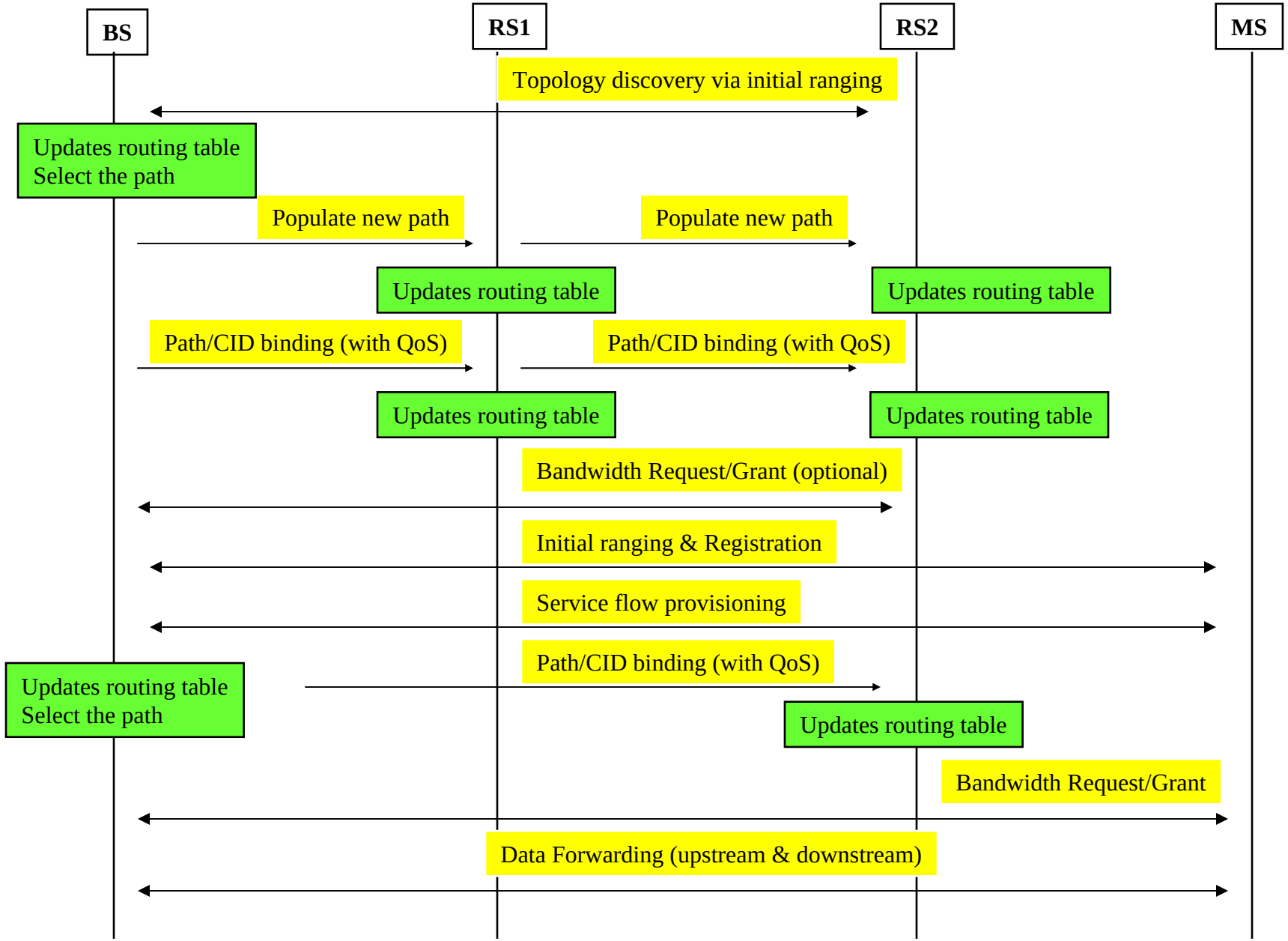
Data Burst Forwarding (2) – Per-Packet Based

- **Distributed routing schema**
  - Destination RS-ID or basic CID is used in MAC header/sub-header to navigate the relay
  - If basic CID is used, the basic CID of destination RS is populated to every RS along the path (via path/CID binding)
  - For the received MPDU, RS checks the destination RS-ID (or basic CID) against the routing table to determines should it further relay the burst or simply drop it.
- **Sourcing routing**
  - Applied to centralized routing. Only BS stores the routing table.
  - The source node specifies the Explicit route in MAC header/sub-header for downstream forwarding
  - The Explicit route consists of BS-ID or based CID

MMR Control Plane Security

- **Peer-to-Peer operation security**
  - .16j only needs consider control plane security over relay links
  - For peer-to-peer unicast management messages, it should follow 802.16-2005 security
  - Peer-to-peer SA associated HMAC is used to authenticate the sender
  - But peer-to-peer messaging causes huge overhead when operations need multiple RS involvement (e.g., path/CID binding)
- **Path-oriented operation security**
  - Many relay operations are associated with paths, and these operations populate the same information to the all RS along a given path
  - MMR cell could be decomposed as security zones
  - In each zone, the RSs share the same group key for path-oriented operations
  - Group key is managed and distributed by BS
  - Per Group SA associated HMAC is used to authenticate the sender
  - Group-cast signaling messages are defined to support path operations
  - Greatly reduce the signaling overhead, especially in RS handover case

MMR Connection Mgmt Call Flows



Summary

1. **This presentation is a summary and harmonization of many proposals from Session #46 contributions**
2. **It systematically discusses the overall MMR end-to-end connection mgmt**
3. **Constraint-Based routing and path/CID binding are proposed to fulfill the requirements of routing and connection mgmt**
4. **Two data forwarding schema could be adopted: connection-based or packet-based**
5. **The harmonized approach would provide a common platform and flexibility to accommodate all contributions for MMR connection mgmt and data forwarding**
6. **The intention is to use this discussion as a basis, to pursue more harmonization, and to provides a guideline for the text description of 802.16j routing and connection management sections.**