Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: **Proposed operational scenarios of L2R networks for TG10 TGD**

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Source: Soo-Young Chang (SYCA), Jaehwan Kim (ETRI), Sangjae Lee (ETRI), and Sangsung Choi (ETRI)
Voice: +1 530 574 2741, E-maill: sychang@ecs.csus.edu

Re: [Subclause 7.1 of 802.15 TG10 TGD]

Abstract: In the TG10 TGD document, operational scenarios are to be included in Subclause 7.1. In the current TGD, 15-13-0753-14, some conflicts may exist between aspects from the scenario described in 7.1 and other TGD requirements. This document is prepared to propose TG10 scenarios which meet all requirements and fit better to real situations.

Purpose: To prepare the operational scenarios to be used for comparison of proposals for TG10.

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- Requirements for scenarios from TGD, 15-13-0753-14
- Proposed operational scenarios for TGD
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  - *Common features for proposed operational scenario*
  - *Operational scenario A: unicast (peer-to-peer)*
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  - *Operational scenario E: linear topology*
- Conclusions

INTRODUCTION

INTRODUCTION

- Operational scenarios are to be included in the TG10 TGD, which can be used to evaluate/compare proposals with the common parameters and environments.

- In this document,
  - All requirements from the current TGD, 15-13-0753-14, to establish operational scenarios, are identified and summarized.
  - All parameters and features which can be applied for these scenarios are defined.

- Several operational scenarios are proposed for various topologies and situations:
  - Scenario A: Unicast
  - Scenario B: Multicast
  - Scenario C: Broadcast
  - Scenario D: Many-to-one
  - Scenario E: Linear topology

REQUIREMENTS FOR SCENARIOS FROM TGD, 15-13-0753-14

REQUIREMENTS FROM TGD (from 15-13-0753-14 Clause 1)

- The use of mesh network topologies
  - Individual nodes have multiple neighbors within communication range
  - Packets traverse the mesh in multiple hops between nodes.
  - Packets can be forwarded through the mesh along a number of possible paths.
  - Nodes make dynamic decisions of which neighbor to forward a packet to, based on knowledge of the current set of available paths, and metrics related to congestion and signal quality.
- Low energy, constrained resource network devices
  - Low data rates: less than 1 Kbps to over 27 Mbps with packet lengths up to 2047 octets in the low kbps range
  - MAC layer design to optimize for very low duty cycle operation and extended sleep time: Even when more practical packet lengths and data rates are considered, the additional delays for synchronizing sleep cycles and multiple hops could easily result in end-to-end delays exceeding several seconds
  - Due to the limited bandwidth of 802.15 networks, the use of broadcast and multicast for establishment and maintenance of bridging operation should be carefully considered, and minimized when possible.

REQUIREMENTS FROM TGD (from 15-13-0753-14 Clause 4)

- Support for multi-hop networks in linear topology for greatest range.
  - Using 802.15.4g for one-to-many and many-to-one topologies. Supporting monitoring applications, with low duty cycle.
- Support for commercial building automation, interior lighting control, street light control, and similar applications
  - These applications have requirements for peer to peer topology (switches or sensors to lights). Many-to-one and one-to-many relationships are required, as well as multicast to support groups of lights. Linear topology is also required for strings of lights. There is sometimes a requirement for mobility to support hand-held controls. There is a requirement for relatively low latency (100mS) for direct manual control of lights.
- Dynamic route reconfiguration
  - Discovery and addition of new nodes
  - Loss and recurrence of routes
  - Support broadcast and multicast: one-to-many and many-to-one topologies with multiple concentrators
- Support for "sleepy nodes", "sleepy routers", and low duty cycle routers
- Routing between different PHYs

REQUIREMENTS FROM TGD (from 15-13-0753-14 Clause 6)

- Possible to merge an independent subnet into a larger network when connectivity between them becomes available, providing both are using similar operating parameters.
  - It should be possible for a network to operate as a number of independent subnets in the event of failure of parts of the network.
- The proposal should provide a method to relearn the network topology in response to changes in the presence of devices, changes in connectivity between devices and changes in the status and quality of the links between devices.
- The proposal should not preclude the use of techniques such as receiver duty-cycling to reduce the power consumption of all devices in the network.
  - The proposal shall support the use of sleeping end and sleeping routing devices.
- It allows data with different properties to be treated differently by the routing algorithm.
  - Such as latency-critical properties over lower-latency paths and higher-priority messages to be transmitted before lower-priority messages over the same link

REQUIREMENTS FROM TGD (from 15-13-0753-14 Clause 6)

- Multiple Entry and Exit points
  - use of multiple ingress and egress points for data within the network to select the most appropriate entry/exit point for their communications with entities outside the network

Some definitions:

Proactive routing: **table-driven routing** by maintaining fresh lists of destinations and their routes by periodically distributing routing tables throughout the network

Reactive routing: on-demand routing by finding a route on demand by flooding the network with Route Request packets

Bridging: to allow two or more communication networks, or two or more network segments, to create an aggregate network, in the first two layers, below the network layer

Routing: to allow the networks to communicate independently as separate networks

Gateway: router or a proxy server that routes between networks,
protocol converters, which can operate at any network layer.

PROPOSED OPERATIONAL SCENARIOS FOR TGD

OPERATIONAL SCENARIO IN THE CURRENT TGD, 15-13-0753-14 (1)

7.1 Scenario for performance requirements comparison

- The following simplified scenario has been defined for the purposes of the Call for Preliminary Proposals (CfPP). As such, the scenario has locked down several aspects, some which may be in conflict with the requirements in the TGD. Proposers are reminded that proposals shall support all aspects of the TGD, even though the scenario to be used for comparison during the CfPP phase has tied some of those down. For the Call for Final Proposals (CfFP) a more extensive scenario(s) will be defined.

CfPP Scenario

- Network Size & Formation
  - PAN coordinator is at the center of the grid
  - During CfPP use 11x11 and 33x33 node networks (99x99 will be added during CfFP)
  - Assume ~static size of network
    - Network has already been initialized and all nodes are on the network

OPERATIONAL SCENARIO IN THE CURRENT TGD, 15-13-0753-14 (2)

CfPP Scenario (cont'd)

- Neighbor Range
  - Nodes have visibility of 3 grid points from itself (neighbor consist of 28 nodes around the node)
  - Packets are subject to loss through contention or collision
- Traffic Pattern
  - Max. of 1 packet at the PAN coordinator every sec. for upstream traffic
  - 127 byte packet lengths are to be used
  - No Downstream or peer-to-peer (this will be specified for the CfFP)
  - (for CfFP the PAN coordinator will send data to each node – specifying the size of packets in bytes and the rate in packets/sec)
- Route Update
  - A random terminal is going off the network every 5min and remains off the network for 10min
  - Route updates every 1min for 11x11
  - Route updates every 10min for 33x33

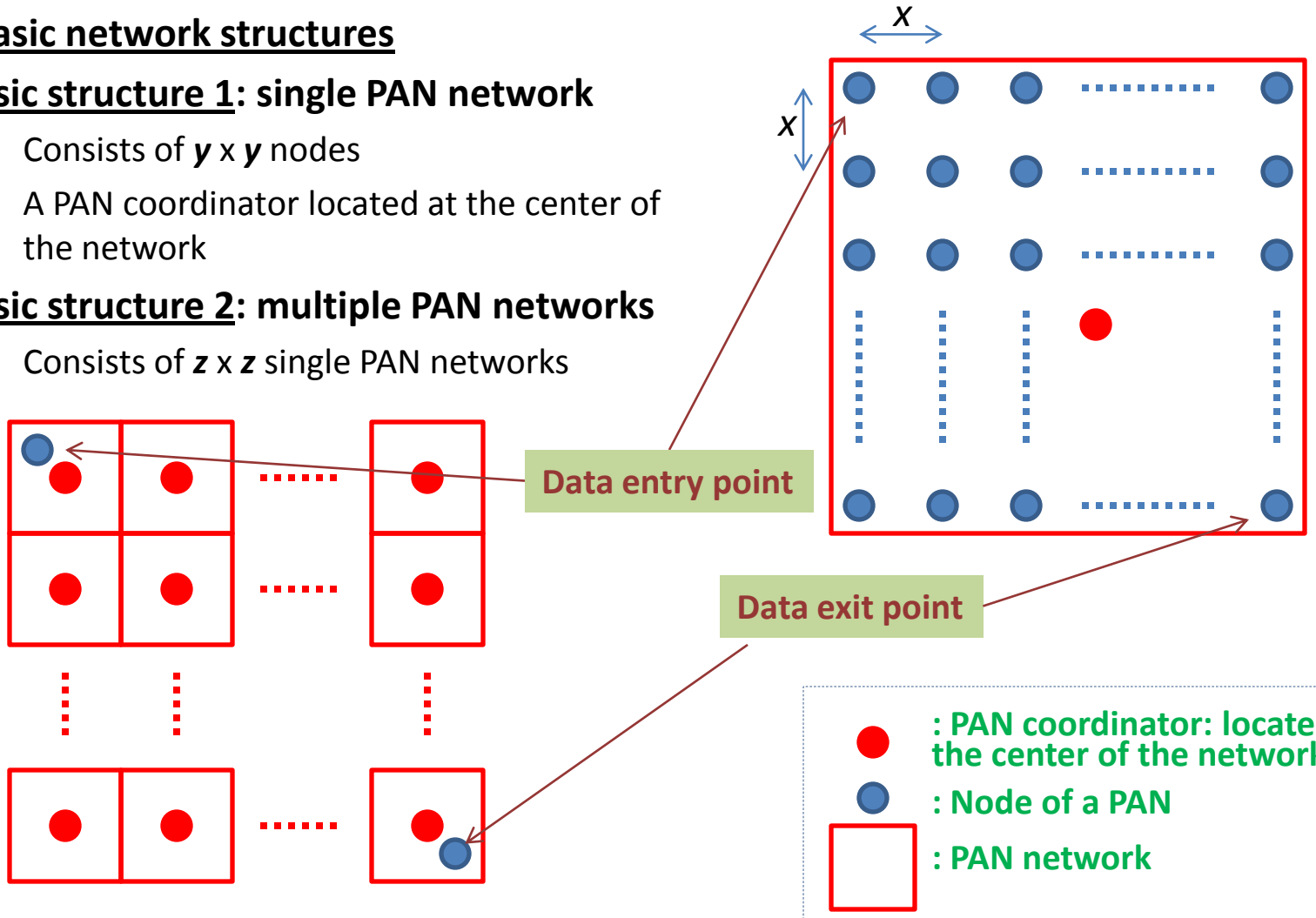
VARIOUS TYPES CONSIDERED FOR PROPOSED OPERATIONAL SCENARIOS

- Two types networks depending on areas/device densities
  - Fixed areas with different device densities
  - Fixed device density with variable sizes of areas due to the number of devices
- Three types of information flow
  - Upstream
  - Downstream
  - Both directions of up and down
- Link failure rates considered for loss of a node (or route) and addition of a new node
  - They are related to link quality and congestion/contention.
- **Link quality can be used for a metric to determine optimal routes.**
  - **Energy detection information and SNR**
- Various types of devices:
  - Origin, neighbors, and destination
  - PAN coordinator and normal node
  - Entry point and exit point
  - Fixed device and mobile device

COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (1)

Two basic network structures

- **Basic structure 1: single PAN network**
  - Consists of ***y*** x ***y*** nodes
  - A PAN coordinator located at the center of the network
- **Basic structure 2: multiple PAN networks**
  - Consists of ***z*** x ***z*** single PAN networks



COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (2)

Traffic pattern

- Thee Data rates: **1 kbps, 200 kbps, and 27 Mbps**
- Three packet sizes: **31 octets, 255 octets, and 2047 octets**

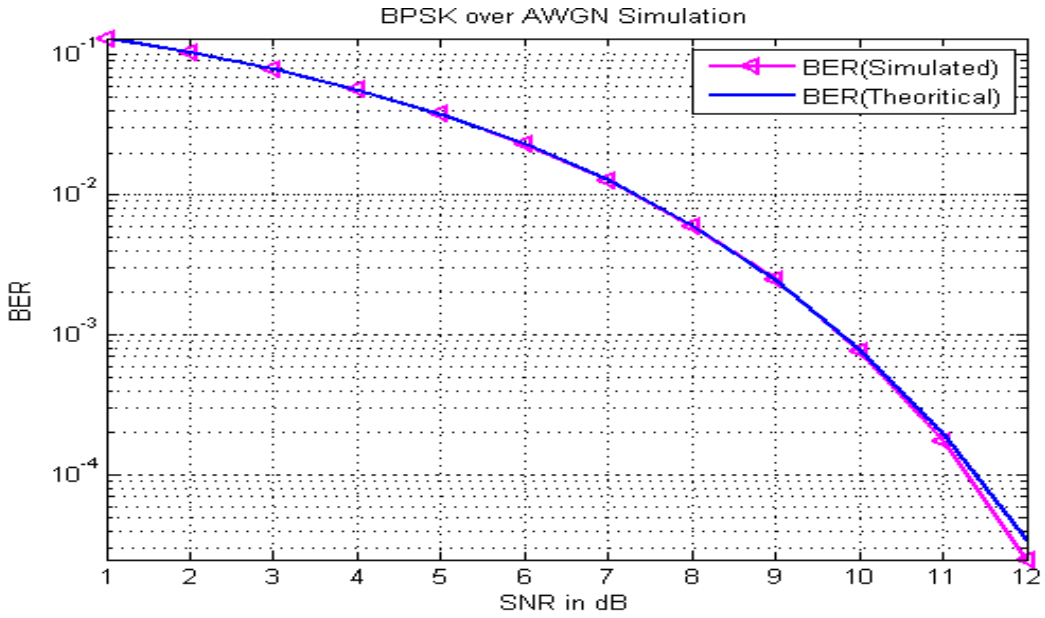
Packet size \ date rate	Packet length in time (sec)		
	1 kbps	250 kbps	27 Mbps
31 octets	0.248	0.00099	9.185×10^{-6}
255 octets	2.04	0.0082	75.56×10^{-6}
2047 octets	16.376	0.0655	606.52×10^{-6}

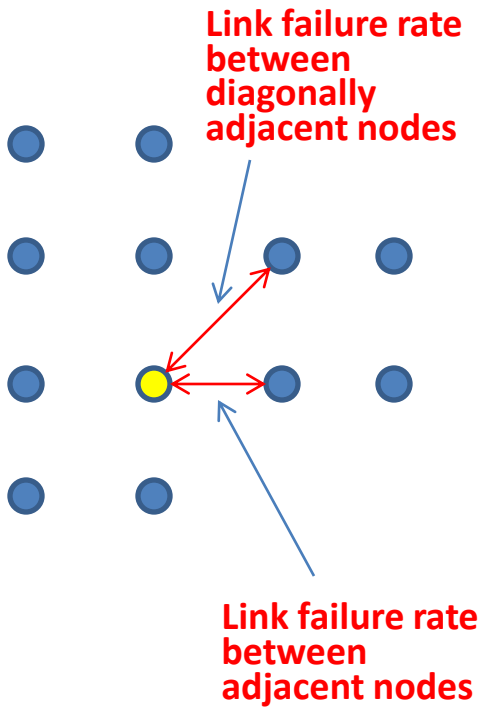
- Low duty cycle operation and extended sleep time: **100% (fully awake), 50%, 10% and 1%**
- Support for “sleepy nodes”, “sleepy routers”, and low duty cycle routers

COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (3)

Signal quality

- **Link failure due to congestion and poor signal quality**: **reflecting** link quality and energy detection information
  - Link failure rates (LFR) between adjacent nodes and between diagonally adjacent nodes respectively : **10^{-1} and $2x10^{-1}$, 10^{-3} and 10^{-2}, 10^{-6} and $2x10^{-5}$**
  - Link failure rates (LFR) between other pairs of nodes: **1**





COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (4)

Signal quality (cont'd)

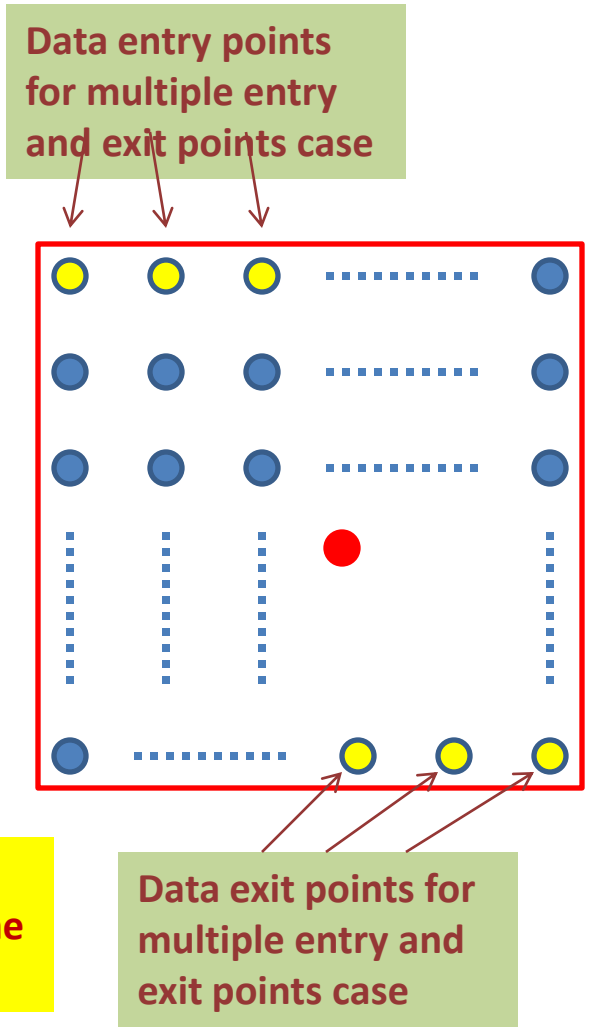
- Link quality can optionally be used for a metric to determine optimal routes.
  - An SNR (or SINR) in dB is assigned to each link randomly among the values below:
    - 0.5, 1.5, 2.5, 3.5, and 4.5

COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (5)

Number of entry and exit points

- **Single Entry and Exit points**
  For each scenario, shown previously
  - entry point: **first node of the first row**
  - exit point: **last node of the last row**
- **Multiple Entry and Exit points**
  For each scenario,
  - entry points: **first three nodes of the first row**
  - exit points: **last three nodes of the last row**
  - use of multiple ingress and egress points for data within the network to select the most appropriate entry/exit point for their communications with entities outside the network

For the multiple PAN network structure, the exit point or points are the last node or the last three nodes of the last row respectively in the right bottom PAN network.



COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (6)

Mobile device as a node

- **For each scenario,** two cases below also to be tested additionally for mobile device as a node
  - Case to consider a mobile device as a sender: **the entry point (or one entry point randomly selected among entry points if there are more than one entry point) is a mobile device**.
  - Case to consider a mobile device as a receiver: **the exit point (or one exit point randomly selected among exit points if there are more than one exit point) is a mobile device**.
  - To meet requirement for mobility to support hand-held controls

Latency-critical messages and high-priority messages

- For each scenario, routes for two types of messages with different properties also to be generated additionally
  - **Case of a latency-critical message to be delivered.**
  - **Case of a high-priority message to be delivered.**
- It allows data with different properties to be treated differently by the routing algorithm.
- Such as latency-critical properties over lower-latency paths and higher-priority messages to be transmitted before lower-priority messages over the same link

COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (7)

Route update with newly added nodes

- For each scenario, route update capability for the case of newly added nodes also to be tested additionally
  - Route update is performed with new link failure rates for all nodes:
    - With new link failure rates, new added nodes will be generated.
    - A new route with a new set of active nodes with a certain link failure rate
  - They will be discovered and added and new routes will be established and route tables will be updated.

COMMON FEATURES FOR PROPOSED OPERATIONAL SCENARIO (8)

Summary of Values applied for Variables

Parameter/description	variable	values
Distance between two nodes in a row (m)	***x***	**2, 5**
Number of nodes in a row and column in a single PAN coordinator network	***y***	**11, 33, 99**
Number of single PAN coordinator networks in a row of a multiple PAN coordinator network	***z***	**1, 3**
Communication range of a node (m)	***w***	**10**
Data rate (kbps)		**1, 200, 27000**
Packet size (octets)		**31, 255, 2047**
duty cycle of operation (%)		**100, 50, 10, 1**
Link failure rates (LFR) of a node due to poor signal quality (LFRs between adjacent nodes and between diagonally adjacent nodes respectively): LFRs between all other pairs of nodes are assumed to be 1.		**10^{-1} and $2x10^{-1}$, 10^{-3} and 10^{-2}, 10^{-6} and $2x10^{-5}$**
SNR (or SINR)		**0.5, 1.5, 2.5, 3.5, and 4.5**

OPERATIONAL SCENARIO A UNICAST (PEER-TO-PEER)

- Basic network structures and parameters and their values to be used
  - ***Specified in the previous slides***

- Two cases applied for data entry and exit points
  - Case for single entry point and single exit point: **use one entry point and one exit point specified**
  - Case for multiple entry and exit points: **use one entry point and exit point selected among three entry points and three exit points respectively**

OPERATIONAL SCENARIO B MULTICAST

- Basic network structures and parameters and their values to be used
  - ***Specified in the previous slides***

- Two cases applied for data entry and exit points
  - Case for single entry point and single exit point: **use one entry point and multicast to three exit points**
  - Case for multiple entry and multiple exit points: **use one entry point selected among three entry points and multicast to three exit points**

OPERATIONAL SCENARIO C BROADCAST

- Basic network structures and parameters and their values to be used
  - ***Specified in the previous slides***

- Two cases applied for data entry and exit points
  - Case for single entry point: **use one entry point and broadcast to all other nodes**
  - Case for multiple entry case: **use one entry point selected among three entry points and broadcast to all other nodes**

OPERATIONAL SCENARIO D MANY-TO-ONE

- Basic network structures and parameters and their values to be used
  - ***Specified in the previous slides***

- Two cases applied for data entry and exit points
  - Case for multiple entry points and single exit points: **use three entry points to send data to one exit point.**
  - Case for multiple entry and multiple exit points: : **use three entry points to send data to one exit point selected among three exit points.**

OPERATIONAL SCENARIO E LINEAR TOPOLOGY

- Basic network structures and parameters and their values to be used
  - ***Specified in the previous slides***

- Two cases applied for data entry and exit points
  - Case for single entry point: **use one entry point to send data to the first node of the last row of the network. This data packet is delivered to the right hand side neighbor node until it reaches to the exit point.**
  - Case for multiple entry points: **select one entry point among three entry points and apply the same procedure for the single entry point case.**

CONCLUSIONS

CONCLUSIONS (1)

- In this document, requirements to establish operational scenarios are identified from the current TG10 TGD, 15-13-0753-14.
- Five operational scenarios are proposed for comparison of the future TG10 proposals:
  - **Scenario A for unicast (peer-to-peer)**
  - **Scenario B for multicast**
  - **Scenario C for broadcast**
  - **Scenario D for many-to-one**
  - **Scenario E for linear topology**
- **Some factors for evaluation criteria of routing algorithms:**
  - **Path length with respect to hop counts**
  - **Latency for a message to travel through routes to destinations**
  - **Memory space to store routing information and overhead**
  - **Processing complexity or computational complexity**
  - **Healing/reconfiguration capability for loss of nodes (or routes) and addition of new nodes**

CONCLUSIONS (2)

Summary of how to meet requirements with the scenarios proposed in this document

Operational requirement	How to evaluate with these scenarios
Various types of topologies	As explained in Scenarios A through E
Route update with signal quality	Link failure rates are used to identify a set of active node at a moment and routes are updated.
Signal quality as a metric	SNR or SINR can be optionally used for a metric to indentify optimal routes only for routing algorithms which use this as a metric.
Multiple entry and exit points	Multiple entry and exit points are shown in the scenarios.
Mobility of devices	A mobile device behaves as an entry device when it sends messages and as an exit device when it receives messages.
Route update with newly added nodes	Application of link failure rates at a moment generates a new set of active nodes, which means loss of links and need of discovery and addition of new nodes. With this new set, routes can be updated.
Routes for higher priority messages	A different routing algorithm is applied to provide routes for higher priority messages.
Routes for lower latency messages	A different routing algorithm is applied to minimize the latency. A different metric may be used to do that.
Multiple subnet	A multiple PAN network structure is introduced.