

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

Submission Title: PHY Proposal with Relaying Support for IEEE802.15.7r1

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Abstract: This contribution presents a partial PHY proposal with relaying support for IEEE 802.15.7r1

Purpose: This is a partial PHY proposal to enable relay-assisted modes.

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- Introduction
- Relaying Operation
- Common Relay Link Setup
- Data Transmission Rules
- Numerical Results: Office Room with Secondary Light Source
- Summary

Introduction (1/3)

Problem statement for VLC channel

- High path loss
 - Large free space path loss
 - Short communication coverage
- High penetration loss by human
 - High penetration loss (e.g., human body ~25 dB)
 - Resulting in no or lower-rate communication between source and destination.

Introduction (2/3)

In order to address the problems, we propose the use of relay mechanisms in VLC systems

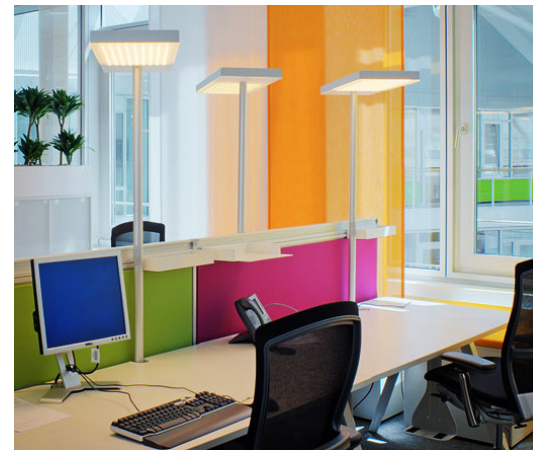
- Relay operation
 - Cooperative Relaying
 - Dual-hop Relaying (Relay is active only when the direct link fails)

Introduction (3/3)

The secondary light sources already exist in the environment can be used as dedicated relay terminals.



Floor light



Desk light

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Relaying Operation (1/5)

1) Cooperative Relaying

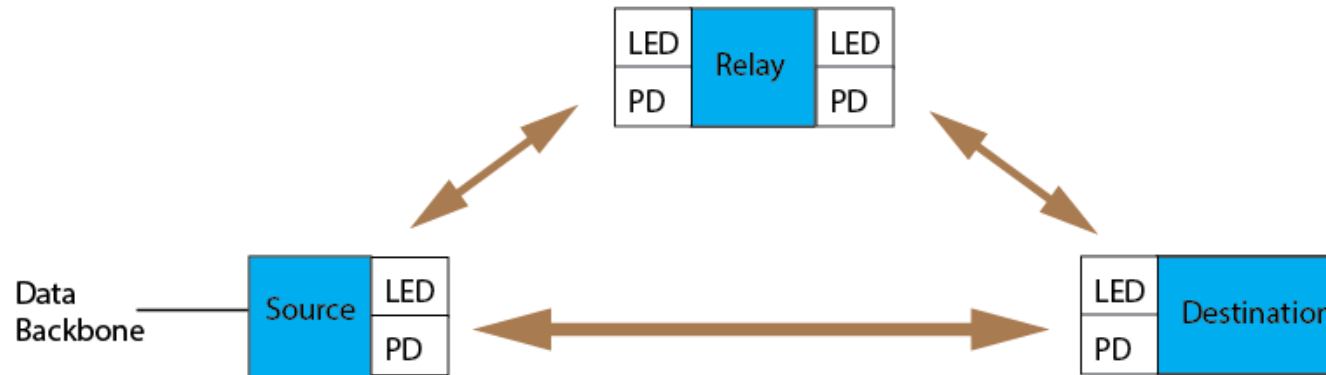
when both S-D and S-R-D links are available

2) Dual-hop Relaying

when S-D link is lost (destination can be blocked or is outside of the coverage), transmission is addressed via relay to destination.

Relaying Operation (2/5)

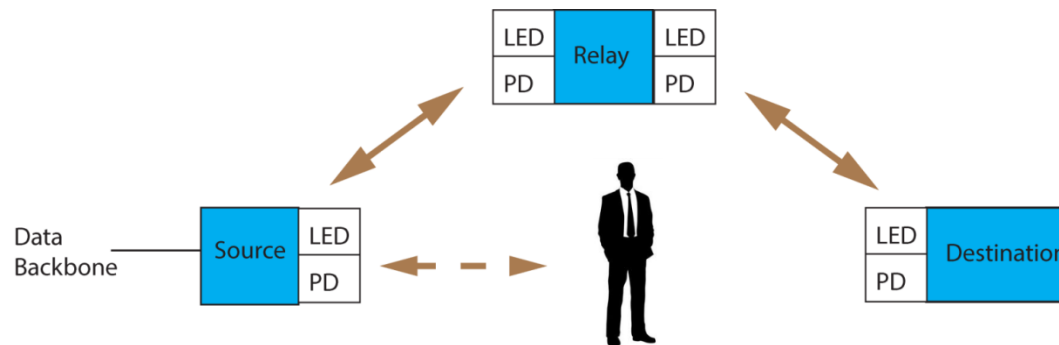
Cooperative Relaying



- The relay is actively involved in the direct link communication between S-D.

Relaying Operation (3/5)

Dual-hop Relaying



- If the S-D PHY link (direct link) is disrupted, transmission of frames addressed to the destination via the relay.
- Direct link can resume after it is recovered.



- If the destination moves outside the coverage area of the source, the transmission of frames addressed to the destination via the relay.
- Direct link can resume after it is recovered.

Relaying Operation (4/5)

The relay can work in one of the AF or DF relaying modes.

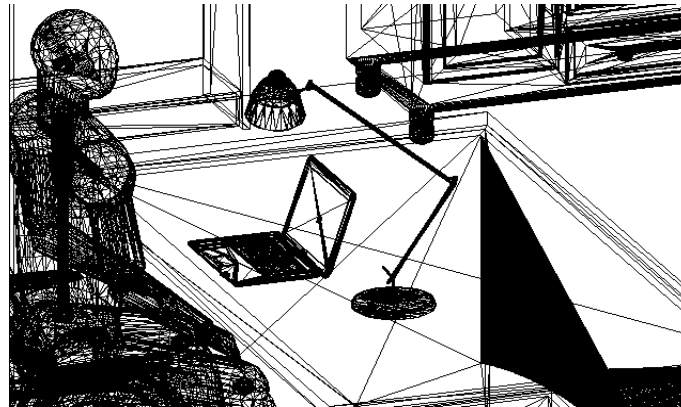
The relay can work in one of the HD or FD duplexing modes.

Full Duplex (FD): The relay receives and transmits simultaneously.

Amplify-and-Forward (AF): The relay amplifies the signal it receives and forwards.

Half Duplex (HD): The relay receives and transmits in different time slots. (i.e. it first receives the frames from the source, and then forwards to destination.)

Decode-and-Forward (DF): The relay decodes the signal it receives, encodes and forwards.



Scenario 2 of IEEE P802.15-15-0746-01-007a.

Relaying Operation (5/5)

In summary, following relaying operation types will be supported.

Cooperative relaying (FD/AF, FD/HD, HD/AF or HD/DF)

Dual-hop relaying (FD/AF, FD/DF, HD/AF or HD/DF)

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- Introduction
- Relaying Operation
- **Common Relay Link Setup**
- Data Transmission Rules
- Relay Operation Type Change
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Common Relay Link Setup (1/9)

In this section, we describe the procedures that a source, a destination and a relay employ to setup a relay operation (either FD/AF or HD/DF).

- **Common Relay Link Setup**
 - Relay capabilities and relay discovery procedures
 - Relay selection procedure
 - Relay link setup (RLS) procedure

Common Relay Link Setup (2/9)

Relay capabilities and relay discovery procedures

- The source that intends to setup relay operation with a destination shall obtain the relay capabilities of the destination and relays prior to initiating the relay setup procedure with the destination.
- Relaying Capabilities Information Element (IE)

Element ID	Length	Relay Capability Info				
		Relay Usability	Relaying mode	Duplexing mode	Operation type	Reserved
Octets : 1	1	B0	B1-B2	B3-B4	B5-B6	B7

Common Relay Link Setup (3/9)

Relay capabilities and relay discovery procedures

- Relaying Capabilities Information Element (IE) (cont'd).
 - The sub-field definition in the Relay Capabilities Info field
 - Relay Usability
 - Indicates that the terminal is capable of relaying.
 - Set to 1 if relay supportable (relay terminal).
 - Otherwise set to 0 (destination terminal).

Element ID	Length	Relay Capability Info				
		Relay Usability	Relaying mode	Duplexing mode	Operation type	Reserved
Octets : 1	1	B0	B1-B2	B3-B4	B5-B6	B7

Common Relay Link Setup (4/9)

Relay capabilities and relay discovery procedures

- Relaying Capabilities Information Element (IE) (cont'd)
 - The sub-field definition in the Relay Capabilities Info field
 - Relaying mode
 - Indicates whether relay is capable of amplify-and-forward (AF) or decode-and-forward (DF) relaying modes.
 - Set to 01 (only AF).
 - Set to 10 (only DF).
 - Set to 11 (both AF and DF). The value 00 is reserved.

Element ID	Length	Relay Capability Info				
		Relay Usability	Relaying mode	Duplexing mode	Operation type	Reserved
Octets : 1	1	B0	B1-B2	B3-B4	B5-B6	B7

Common Relay Link Setup (5/9)

Relay capabilities and relay discovery procedures

- Relaying Capabilities Information Element (IE) (cont'd)
 - The sub-field definition in the Relay Capabilities Info field
 - Duplexing mode
 - Indicates whether terminal (either relay or destination) is capable of full-duplex (FD) or half duplex (HD) duplexing modes.
 - Set to 01 (only FD).
 - Set to 10 (only HD).
 - Set to 11 (both FD and HD). The value 00 is reserved.

Element ID	Length	Relay Capability Info				
		Relay Usability	Relaying mode	Duplexing mode	Operation type	Reserved
Octets : 1	1	B0	B1-B2	B3-B4	B5-B6	B7

Common Relay Link Setup (6/9)

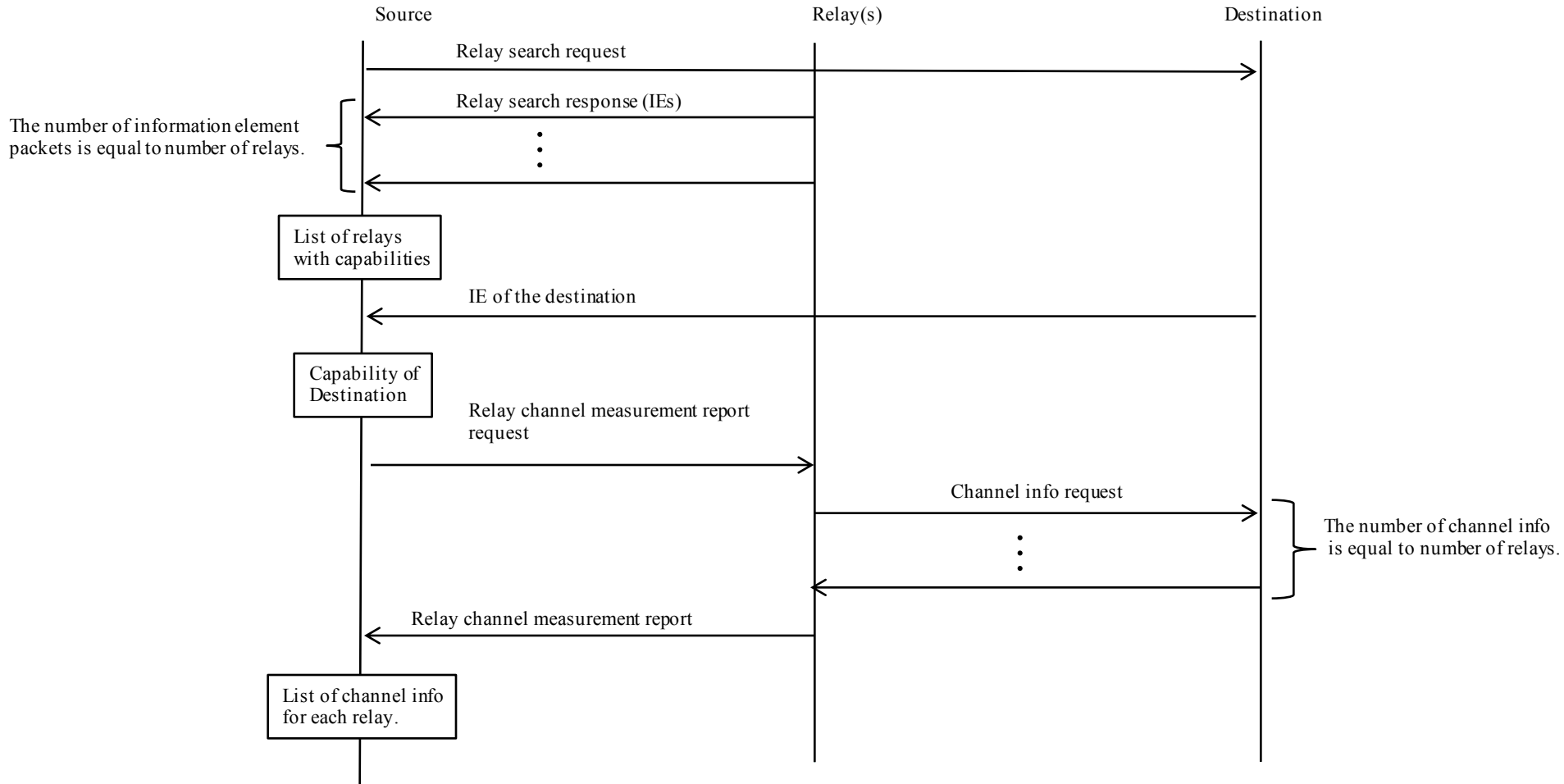
Relay capabilities and relay discovery procedures

- Relaying Capabilities Information Element (IE) (cont'd)
 - The sub-field definition in the Relay Capabilities Info field
 - Operation type
 - Indicates whether the terminal (either relay or destination) is capable of cooperation relaying or dual-hop relaying.
 - Set to 01 (only cooperation).
 - Set to 10 (only dual-hop).
 - Set to 11 (both cooperation and dual-hop). The value 00 is reserved.

Element ID	Length	Relay Capability Info				
		Relay Usability	Relaying mode	Duplexing mode	Operation type	Reserved
Octets : 1	1	B0	B1-B2	B3-B4	B5-B6	B7

Common Relay Link Setup (7/9)

Relay capabilities and relay discovery procedures



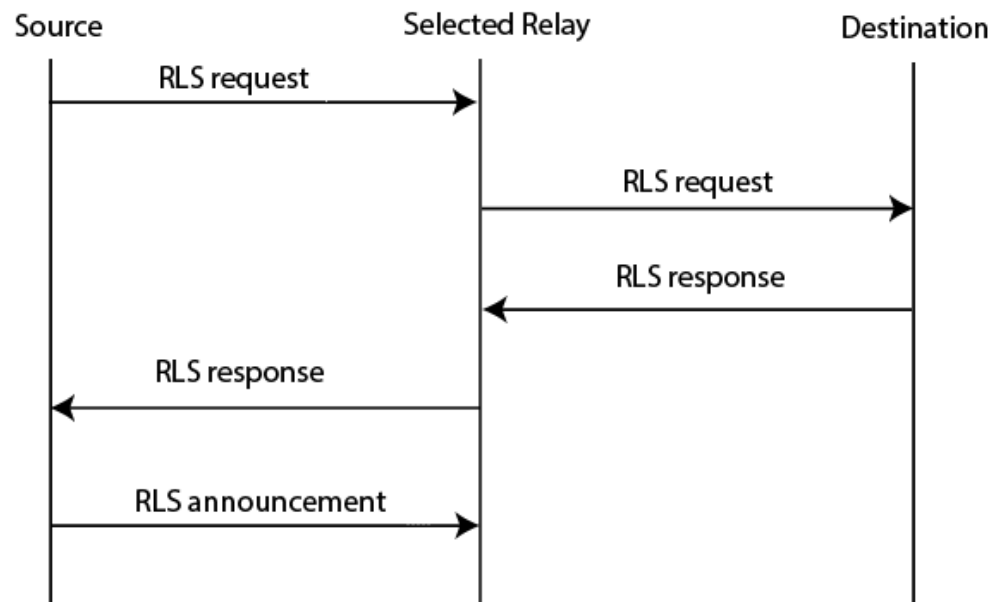
Common Relay Link Setup (8/9)

Relay selection procedure

- For each destination terminal appropriate relay is selected according to the channel conditions.

Common Relay Link Setup (9/9)

Relay link setup (RLS) procedure



RLS request: including capabilities, IDs of the source, relay, destination nodes.

RLS response: indicates whether terminal can participate in the RLS.

RLS announcement: indicates the RLS procedure was successfully completed.

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- Introduction
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Data Transmission Rules (1/6)

In this section, we describe the data transmission rules for the following relaying operation types.

- 1) **Cooperative relaying** (FD/AF, FD/DF, HD/AF or HD/DF)
- 2) **Dual-hop relaying** (FD/AF, FD/DF, HD/AF or HD/DF)

Data Transmission Rules (2/6)

1) Cooperative relaying (FD/AF, FD/HD)

A source shall use the relay (both S-D and S-R-D links) when it initiates frame transmission to the destination at the start of the first SP allocated for destination.

Relay works in FD mode.



Delay due to the processing time of the FD relay

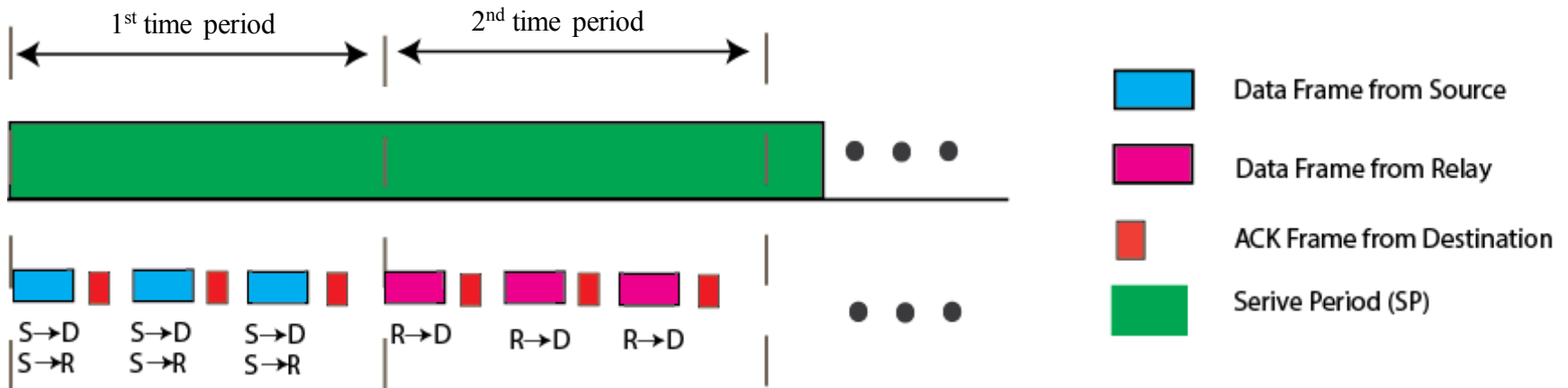
Data Transmission Rules (3/6)

1) Cooperative relaying (HD/AF or HD/DF)

A source shall use the relay (both S-D and S-R-D links) when it initiates frame transmission to the destination at the start of the first SP allocated for destination.

Relay works in HD mode.

Destination applies a combining scheme (Selection combining, Maximal ratio combining etc.).



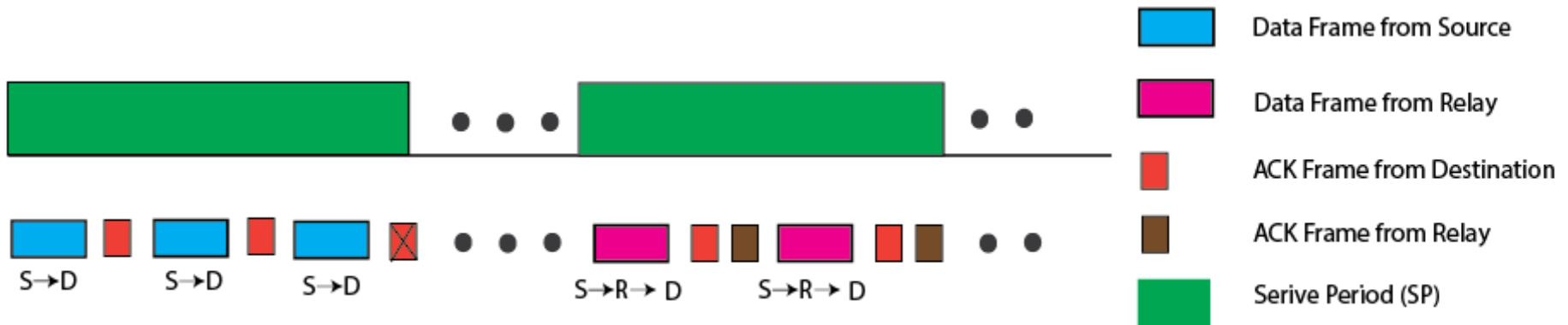
Data Transmission Rules (4/6)

2) Dual-hop relaying (FD/AF, FD/DF)

A source shall use the direct link (S-D) to initiate frame transmission to the destination at the start of the first SP allocated for destination.

If the “ACK frame to Direct link” fails (either due to blocking or lack of coverage), transmission is addressed via relay to destination.

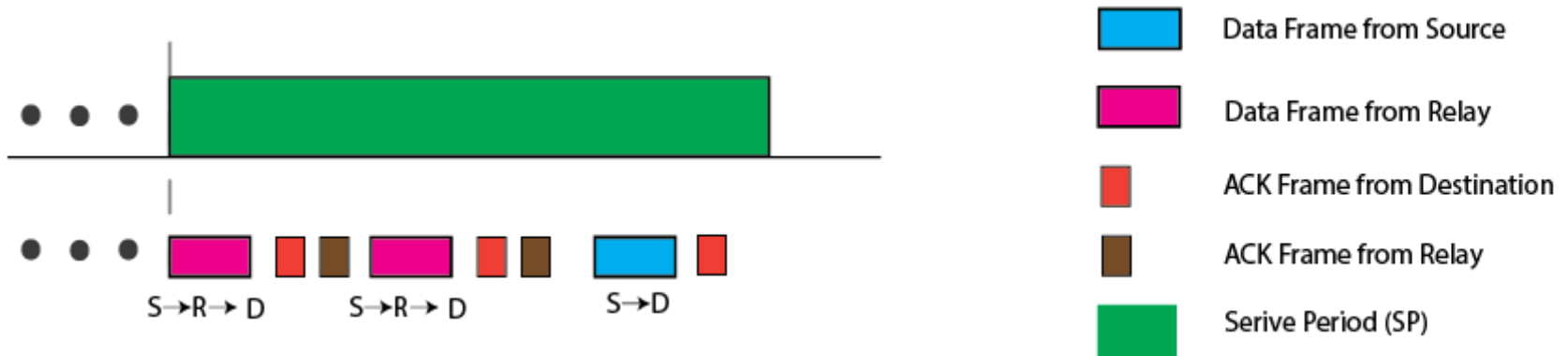
Relay works in FD mode.



Data Transmission Rules (5/6)

2) Dual-hop relaying (FD/AF, FD/DF) cont'd

After transmitting a series of frames via relay, source retries the transmission through S-D link. If it receives "ACK Frame to Direct link", it resumes S-D link. Otherwise, it switches back to relaying.



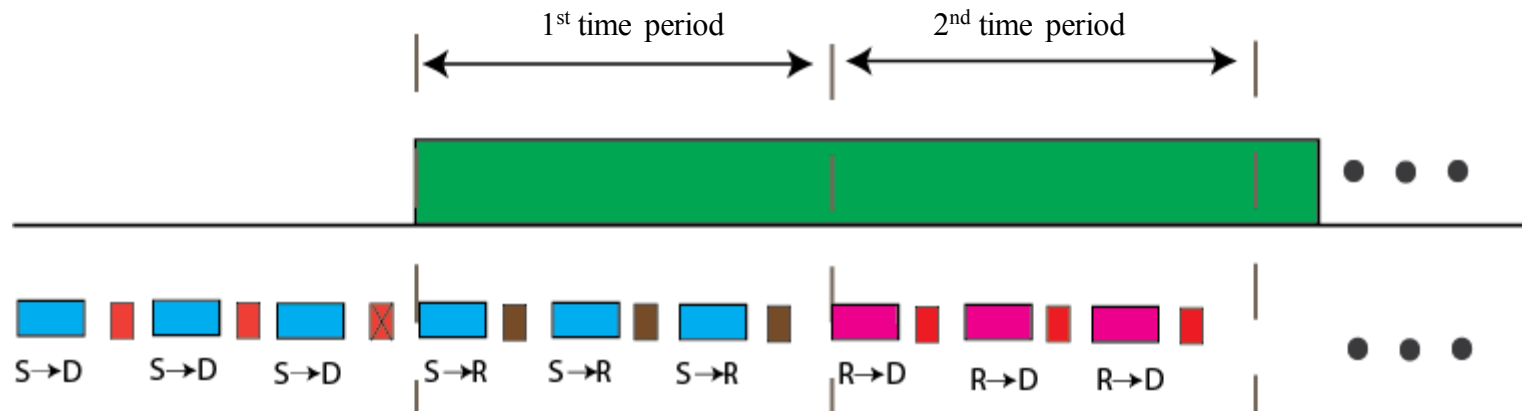
Data Transmission Rules (6/6)

2) Dual-hop relaying (HD/AF or HD/DF)

A source shall use the direct link (S-D) to initiate frame transmission to the destination at the start of the first SP allocated for destination.

Relay works in HD mode.

Destination applies a combining scheme (Selection Combining, Maximal ratio combining etc.).

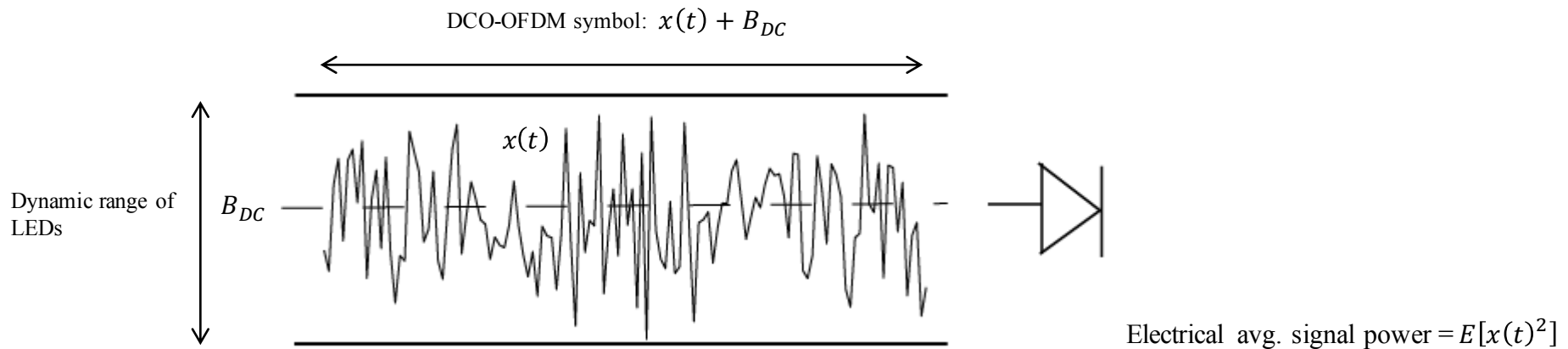


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Numerical Results

- DCO-OFDM
- Pulse shaping filter: Root raised cosine
- Bandwidth (W): 10 MHz
- Number of subcarrier: 64
- Cyclic prefix length: 3
- Noise power spectral density (N_0): 10^{-22} W/Hz

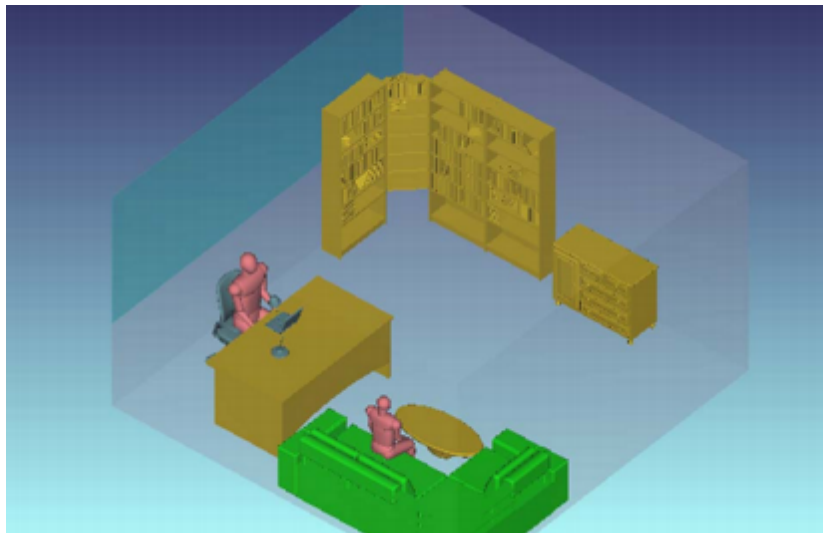


Example 1: Office Room with Secondary Light Source

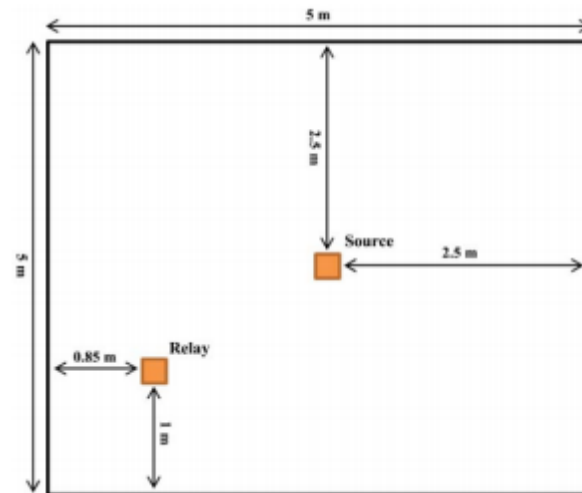
Both S-D and S-R-D links are available. The relay is actively involved in the direct link communication between S-D.

Cooperative relaying (HD/DF, HD/AF, FD/DF or FD/AF)

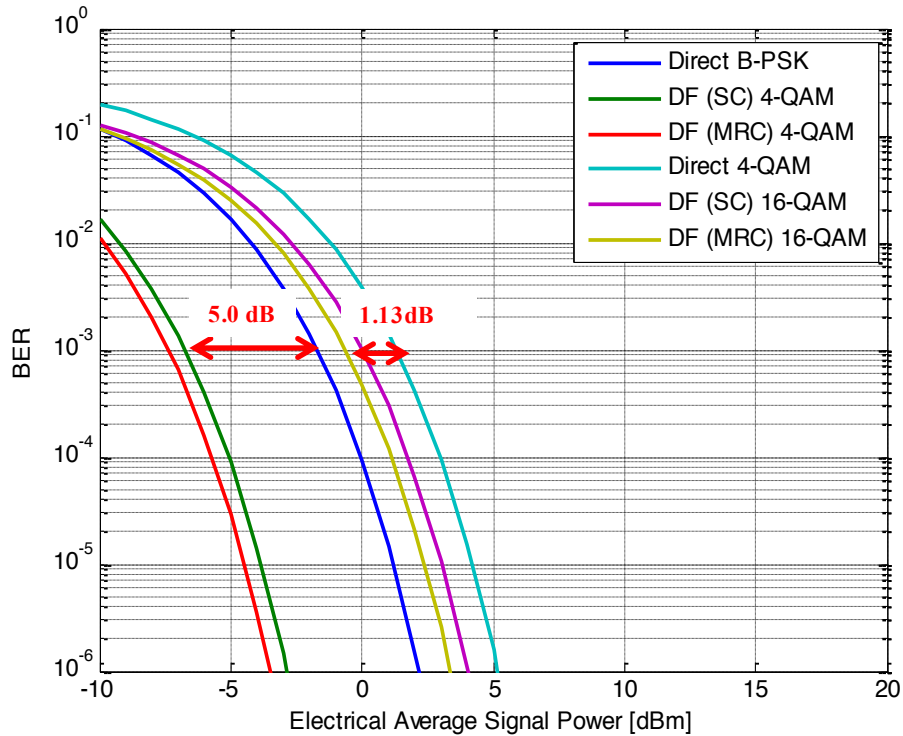
Scenario 2 from IEEE P802.15-15-0746-01-007a.



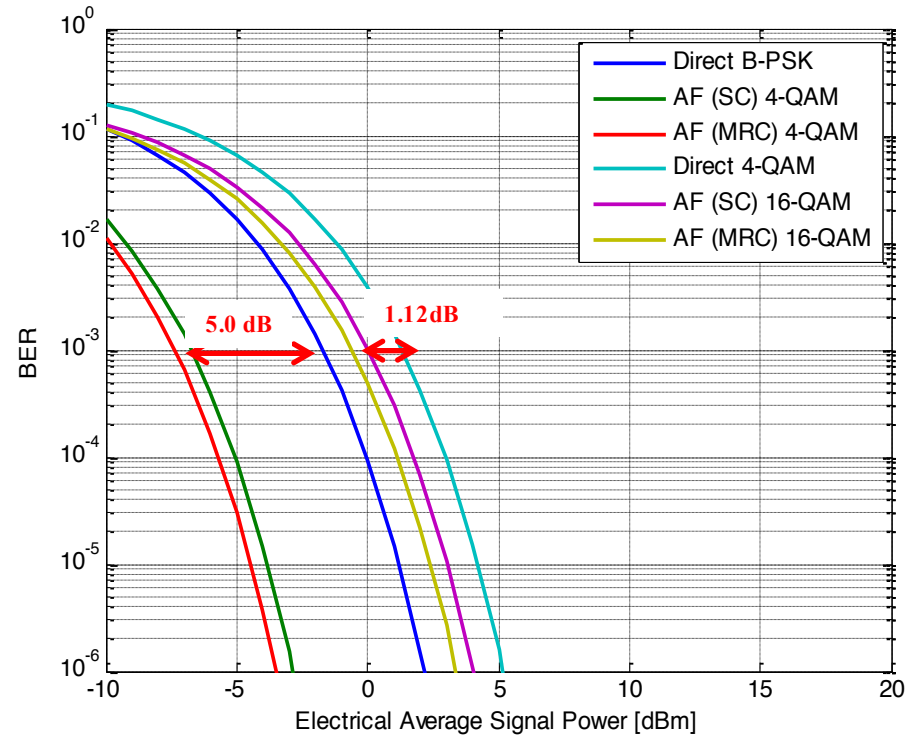
Secondary light source is in the form a desk light.



Half duplex DF



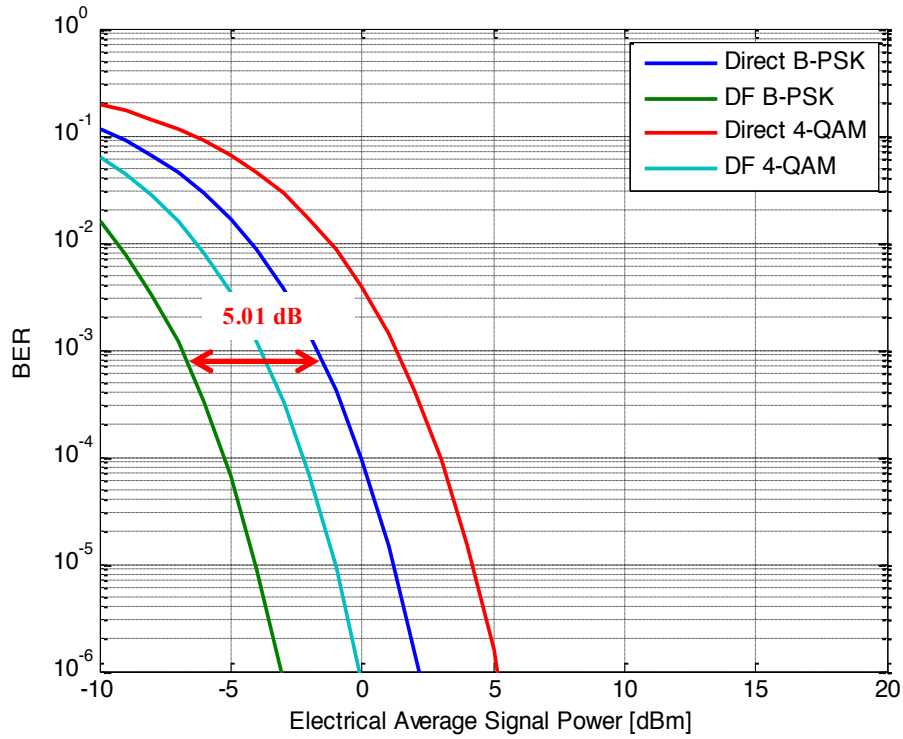
Half duplex AF



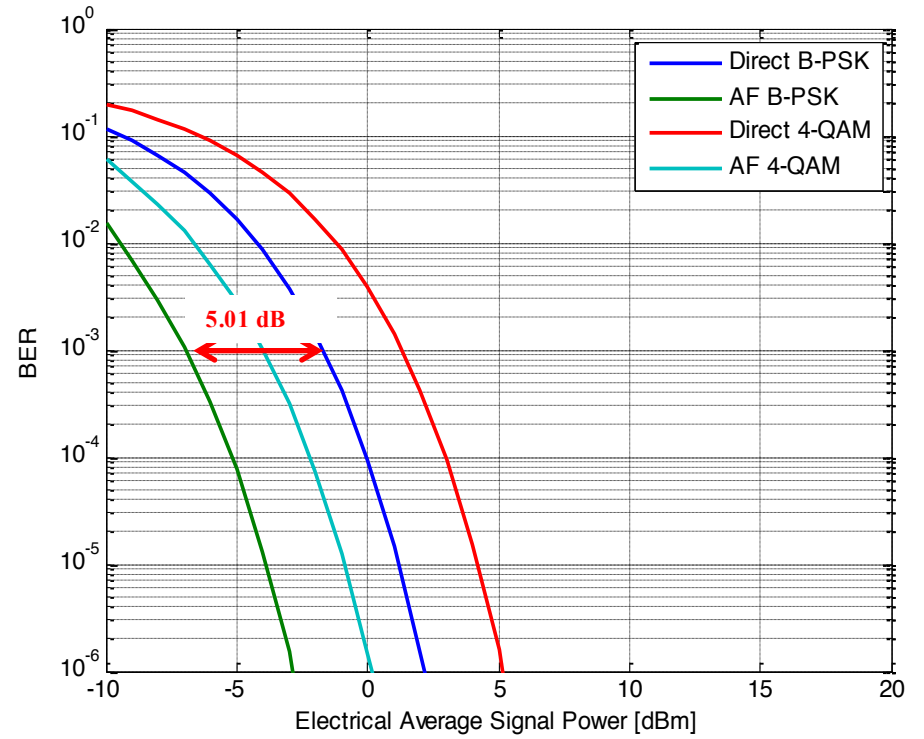
Gains are given based on Selection Combining.

BER curves with Maximal Ratio Combining (MRC) are given for reference. The improvements with MRC are limited.

Full duplex DF



Full duplex AF

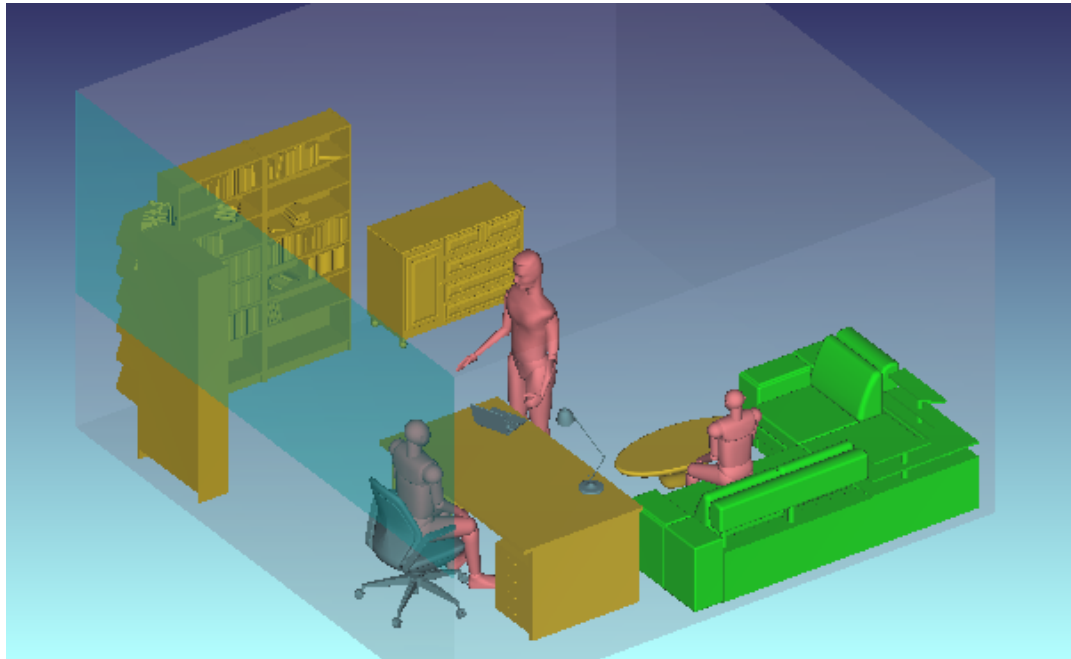


Gain is fixed for any modulation order.
 In FD relaying, SNR is gain obtained.

Example 2: Office Room with Secondary Light Source, S-D link is blocked

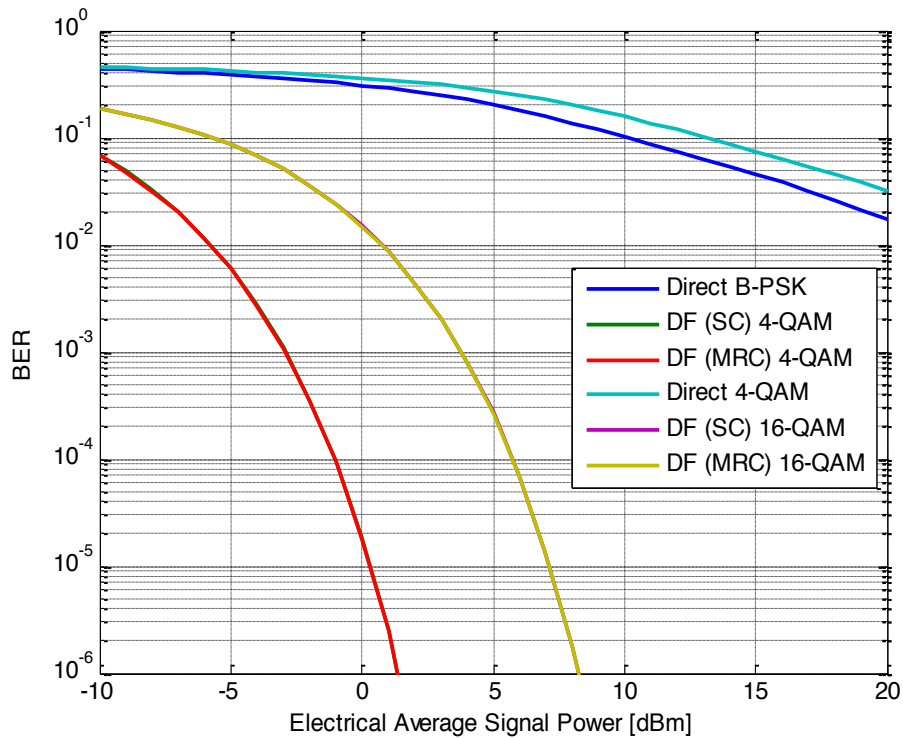
Both S-D and S-R-D links are available. The relay is actively involved in the direct link communication between S-D.

Dual-hop relaying (HD/DF, HD/AF, FD/DF or FD/AF)

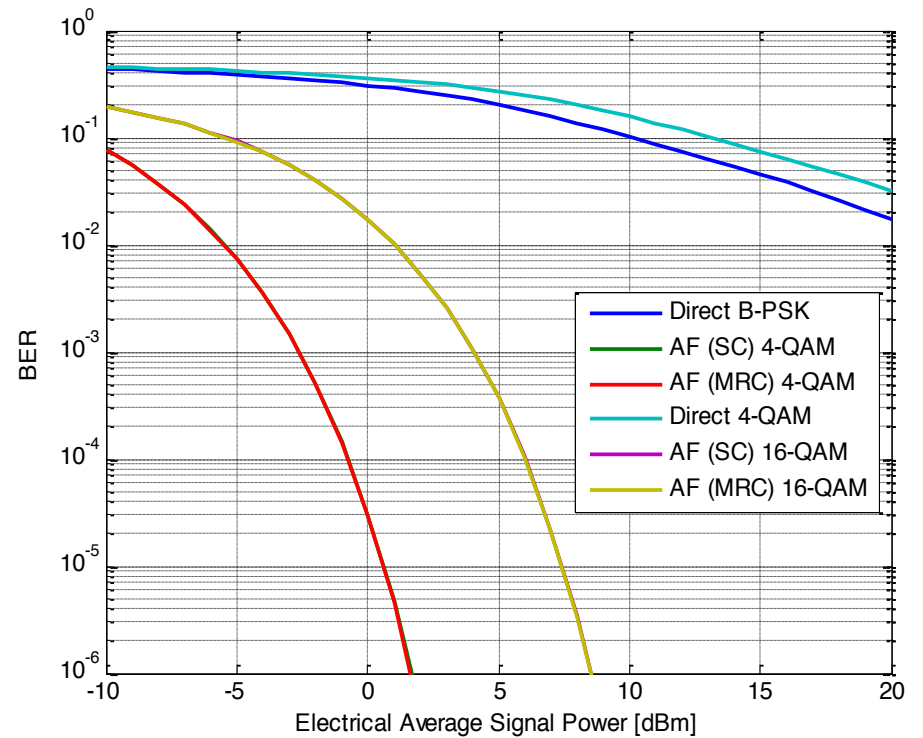


**Penetration loss in
S-D link due to
human blockage:
~25 dB**

Half duplex DF



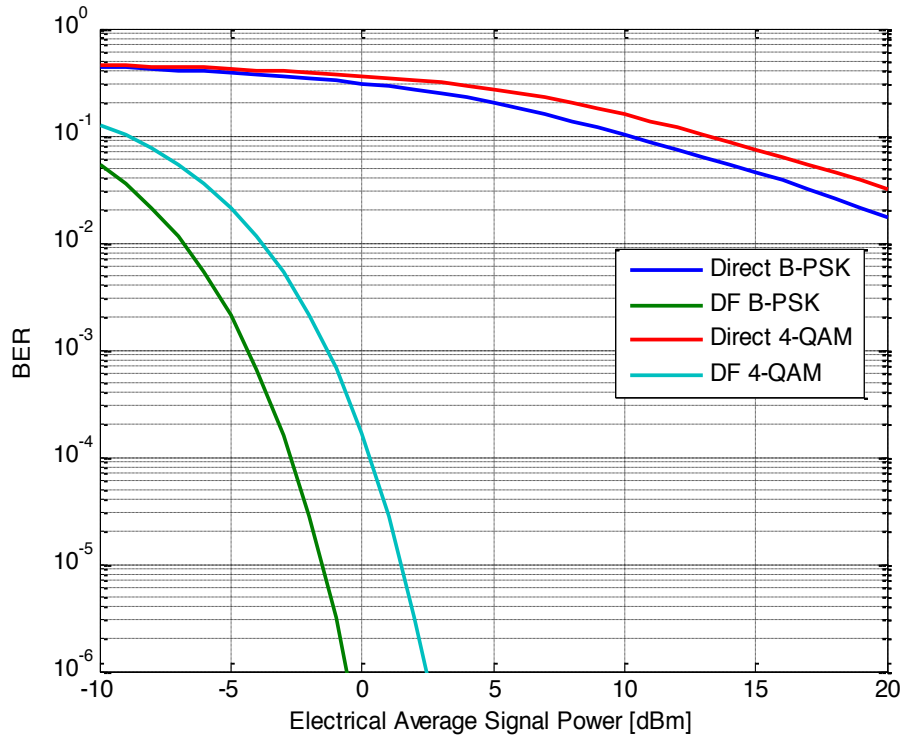
Half duplex AF



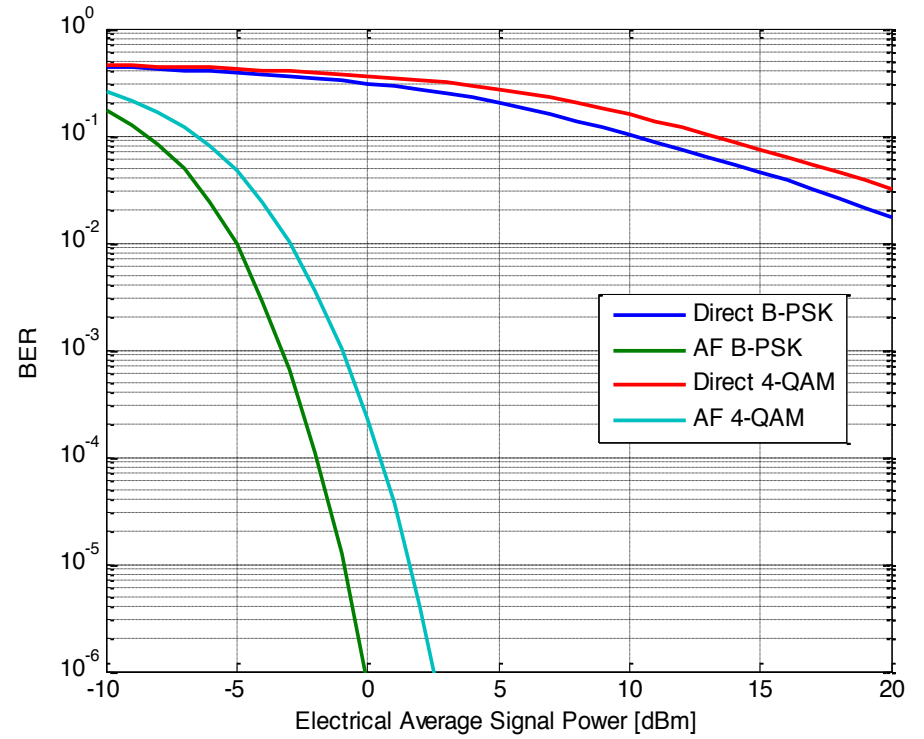
Selection combining (SC) and Maximal Ratio Combining (MRC) gives

Gain is 32.0 dB for AF , 32.3 dB for DF

Full duplex DF



Full duplex AF



Gain is 34.21 dB for AF , 34.29 dB for DF.

Summary

- Proposed relaying support techniques for IEEE 802.15.7.r1
- Two relaying operation: cooperative and dual-hop relaying.
- For each operation, we consider different duplexing and modes:
 - Duplexing: Half-Duplex (HD) and Full-Duplex (FD).
 - Modes: Amplify-and-Forward (AF) and Decode-and-Forward (DF).
- Gain of cooperative operation: 1.12-5.3 dB depends on modulation level.
- Gain of dual-hop operation: ~34.3 dB.