802.22b NICT Proposal

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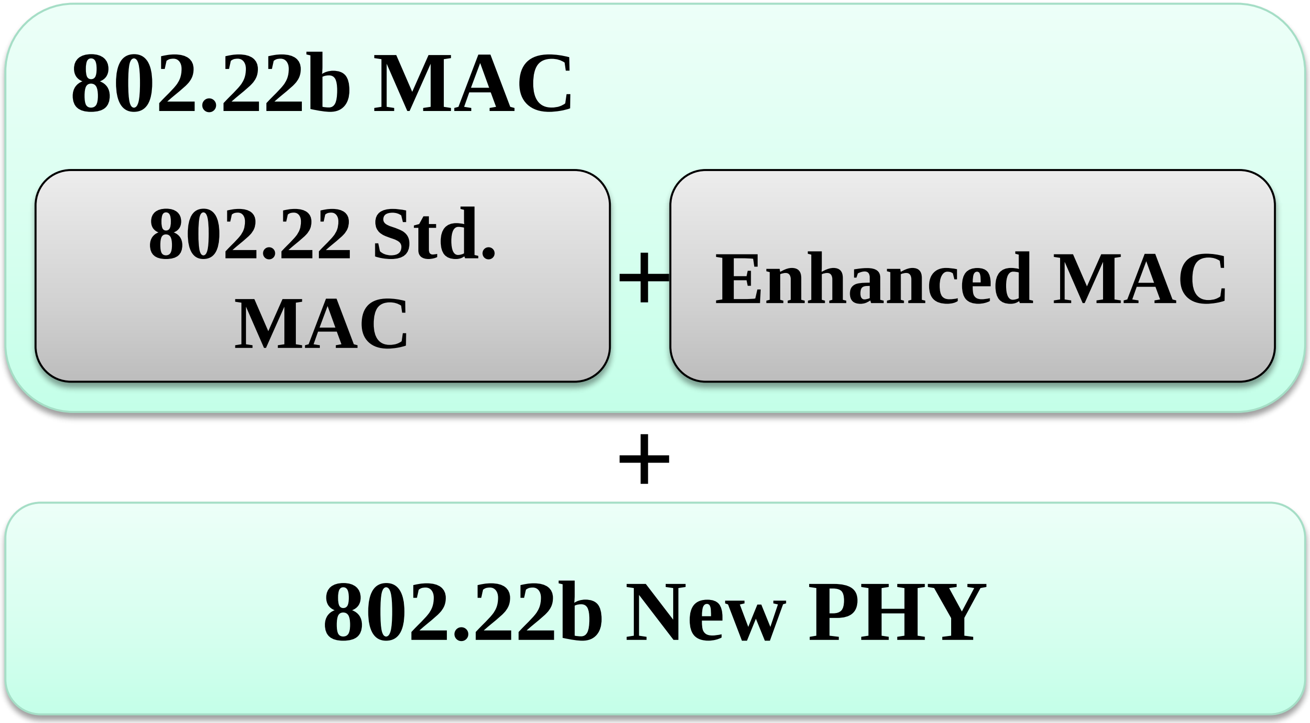
Summary

- This document proposes P802.22b PHY & MAC, and shows the performance
- **NICT proposal meets PAR Scope and all mandatory Requirements**
  - For 802.22b Network
    - Supports different capability classes of devices (PAR Scope, Requirement 03)
    - Supports larger network capacity (PAR Scope, Requirement 05)
    - Supports multi-hop (relay) connectivity (Requirements 06, 07)
  - For 802.22b PHY
    - Supports low complexity/capability design (PAR Scope)
    - Supports cost-effective compliance with regulatory spectral mask (Requirements 01, 12)
    - Supports higher data rates (PAR Scope, Requirement 02)
  - For 802.22b MAC
    - Supports enhanced channel utilization (Requirement 08)
    - Supports multi-channel utilization (PAR Scope, Requirement 02)
    - Supports enhanced frame transmission and addressing (Requirements 04, 09)
    - Supports enhanced management (Requirements 10, 11)

802.22b System Overview



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- **802.22b Proposal**
  - 802.22b Network
    - Network Configuration
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  - PHY Layer
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    - MIMO
  - 802.22b OFDMA Frame
    - OFDMA Frame Format
    - Multi-hop Frame Allocation and Re-use
  - MAC Layer
    - 802.22b Operations
    - Enhanced Management
- **802.22b Performance**
  - Network Capacity
  - Throughput, Delay, Packet Error Rate

802.22b Network

802.22b Network

- To realize the both service applications of infrastructure monitoring & metering and broadband service extension, an 802.22b network
  - supports different capability device classes
  - supports large network capacity
  - supports multi-hop (relay) connectivity

- **802.22b Devices (FCC Mode)**
  - **802.22b BS** (Base Station)
    - Fixed Mode
  - **H-CPE** (High-capability Consumer Premise Entity)
    - Fixed Mode or Personal/Portable Mode II
  - **L-CPE** (Low-capability Consumer Premise Entity)
    - Fixed Mode, Personal/Portable Mode II or Mode I

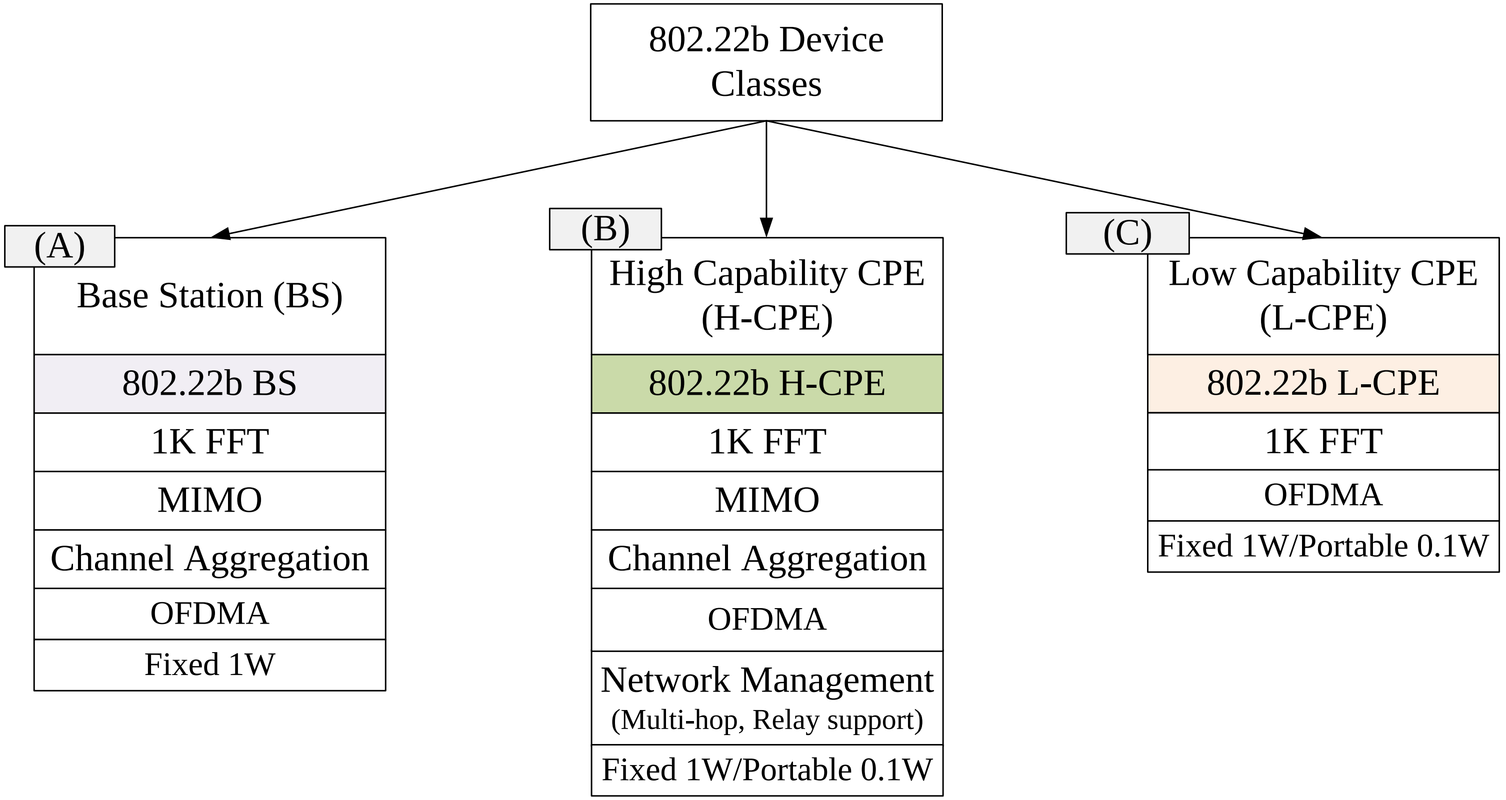
802.22b Network

- **Device Class and Capabilities**

Device Class	Network Devices	Major Capabilities	Modifications from 802.22 Standards
Class (A)	802.22b BS	• MIMO Support • Channel Aggregation Support • Management of a whole network • 1K FFT	- MIMO - Channel Aggregation - Multi-hop - Enhanced PHY - Enhanced MAC
Class (B)	H-CPE	• MIMO Support • Channel Aggregation Support • Management of L-CPEs • Multi-hop (relay) Support • 1K FFT	
Class (C)	L-CPE	• 1K FFT	

802.22b Network

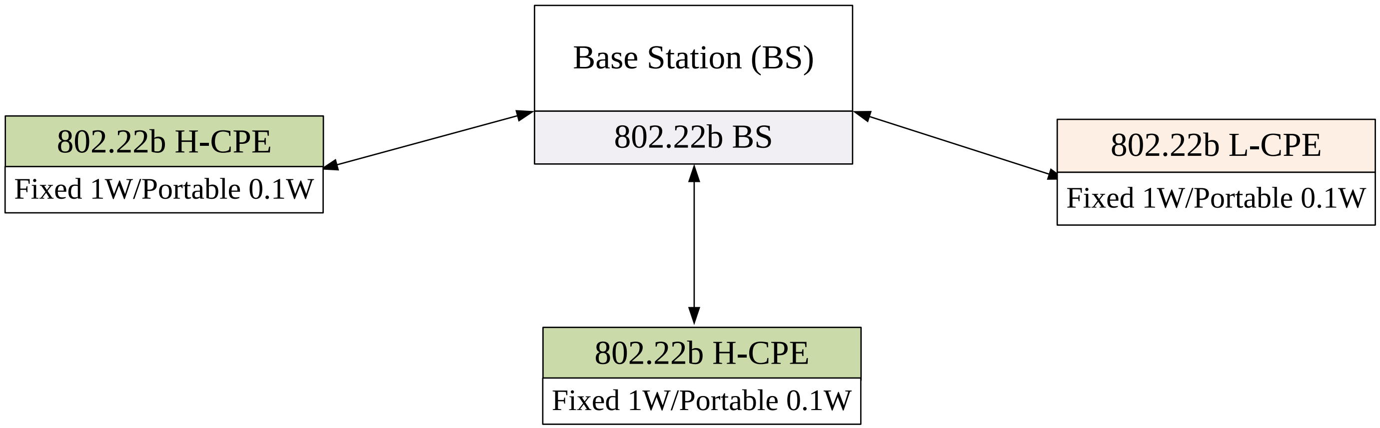
- **Device Classes on Capability**



802.22b Communications

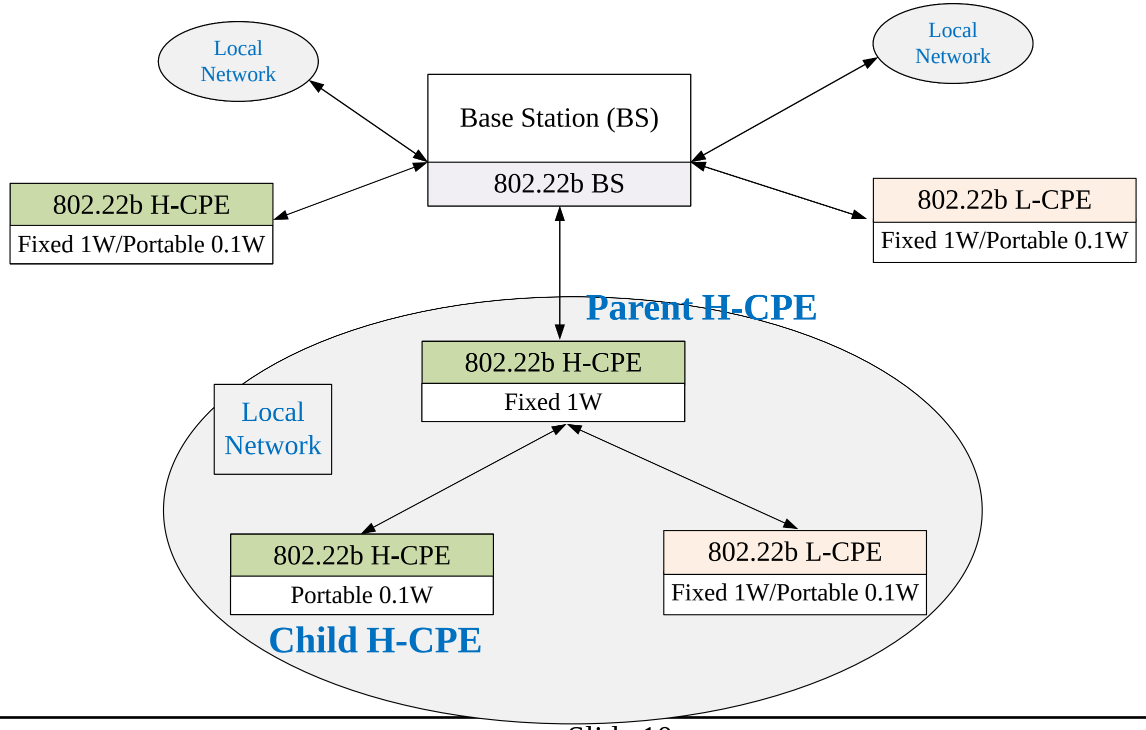
- **802.22b supports two types of communication**
  - Direct Communication
  - Multi-hop Communication

- **Direct Communication**
  - 802.22b CPEs (H-CPE and L-CPE) can communicate with BS directly
  - Example of direct communication



802.22b Communications

- **Multi-hop Communication**
  - 802.22b CPEs (H-CPE and L-CPE) can communicate with BS through H-CPE
    - Parent H-CPE which provides connection for other H-CPEs or L-CPEs
    - Child H-CPE which is managed by the parent H-CPE
    - A local network, which is managed by a H-CPE, contains more than one 802.22b CPEs
  - Example of multi-hop communication



802.22b Network Communications

- **Summary of Communication Types**

Communication Type	Base Station	Middle Device	End Device
Direct Communication	BS (Class A)	-	H-CPE (Class B) / L-CPE (Class C)
Multi-hop Communication	BS (Class A)	H-CPE (Class B)	H-CPE (Class B) / L-CPE (Class C)

802.22b PHY

802.22b PHY Motivation

- To realize the applications of critical infrastructure monitoring & metering and broadband service extension, 802.22b PHY needs to
  - support low complexity design
  - support higher data rates
  - support feasibility and cost-effective compliance with regulatory spectral mask
  - support reliable communications

802.22b PHY Parameters

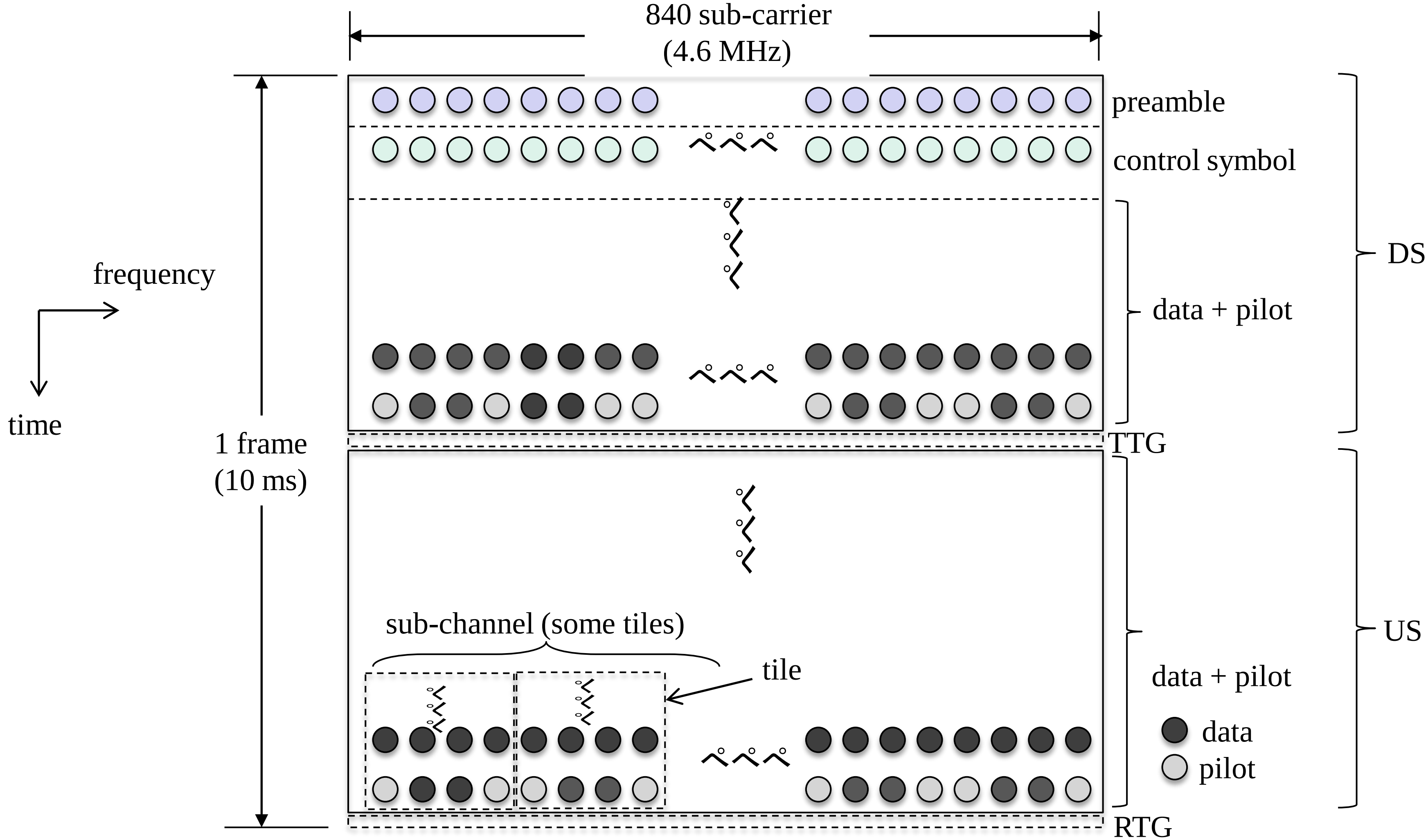
	802.22b		
Channel bandwidth	6	MHz	
FFT size	1024	carriers	
Sampling frequency	5.600	MHz	
Sampling period (time unit: TU)	178.571	usec	
Carrier spacing	5.469	kHz	
Number of subchannels	52	sub-channels	DS
	105	sub-channels	US
Number of null carriers (L, DC, R)	192	carriers	DS
	184	carriers	US
Number of used carriers	832	carriers	DS
	840	carriers	US
Occupied bandwidth	4.550	MHz	DS
	4.594	MHz	US
Lower channel edge guardband	726.4	kHz	DS
	704.5	kHz	US
Upper channel edge guardband	723.6	kHz	DS
	701.8	kHz	US

Cyclic prefix	1/4	1/8	1/16	1/32	
Useful symbol period	182.857				usec
Cyclic prefix duration	45.714	22.857	11.429	5.714	usec
Total symbol period	228.571	205.714	194.286	188.571	usec

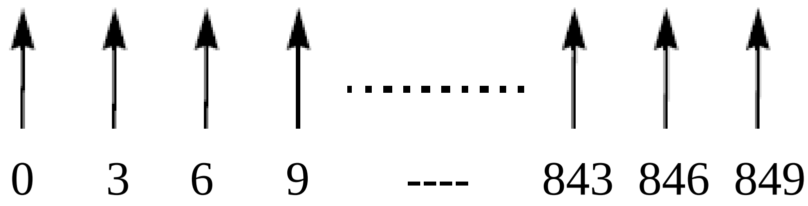
802.22 vs. 802.22b

	802.22	802.22b		
Duplex mode	TDD	TDD		
Multiplex mode	OFDMA	OFDMA		
Channel bandwidth	6	6	MHz	
FFT size	2048	1024	carriers	
Sampling frequency	6.857	5.600	MHz	
Sampling period	145.833	178.571	usec	
Carrier spacing	3.348	5.469	kHz	
Useful symbol period	298.667	182.857	usec	
Cyclic prefix (1/32)	9.333	5.714	usec	
Total symbol period	308.000	188.571	usec	
Number of null carriers (L, DC, R)	368	192	carriers	DS
		184		US
Number of used carriers	1680	832	carriers	DS
		840		US
Occupied bandwidth	5.625	4.55	MHz	DS
		4.594		US
Lower channel edge guardband	188.3	726.4	kHz	DS
		704.4		US
Upper channel edge guardband	186.7	723.6	kHz	DS
		701.6		US

General description of 22b frame structure



Some 22b PHY specs different from 22
-Preamble-



Basic structure of DS preamble

$\mathrm{PreambleCarrierSet}_n = n+3k$ (n= 0, 1, 2, k=0,1, ---, 283)

Some 22b PHY specs different from 22
-Subcarrier Allocation-

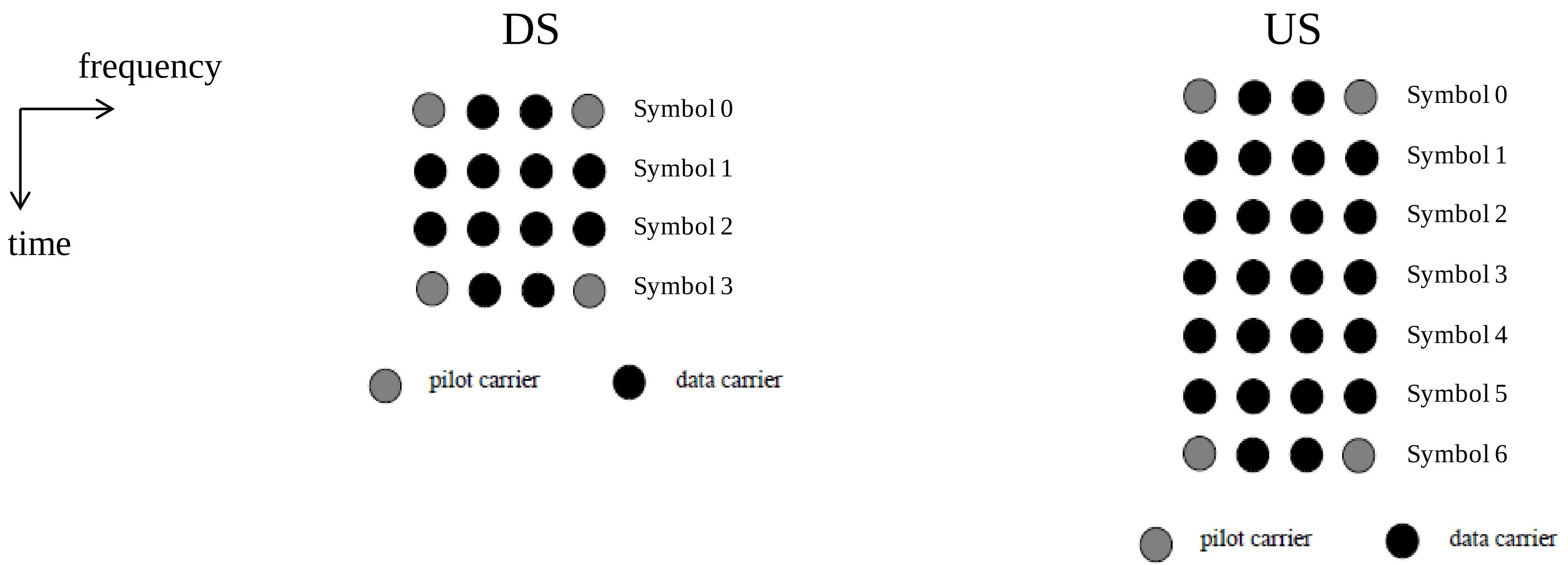
DS

Parameters	Value	Notes
Number of DC subcarriers	1	
N_{used}	833	Number of all subcarriers used within a symbol
Guard Subcarriers: left, right	96, 95	–
Tile Permutation	{ 6, 48, 37, 21, 31, 40, 42, 32, 47, 30, 33, 18, 10, 15, 50, 51, 46, 23, 45, 16, 39, 35, 7, 25, 11, 22, 38, 28, 19, 17, 3, 27, 12, 29, 26, 5, 41, 49, 44, 9, 8, 1, 13, 36, 14, 43, 2, 20, 24, 4,34, 0}	Used to allocate tiles to subchannels
$N_{subchannels}$	52	–
N_{tiles}	208	–
Number of subcarriers per tile	4	Number of all subcarriers used within tile
Tiles per subchannel	4	–

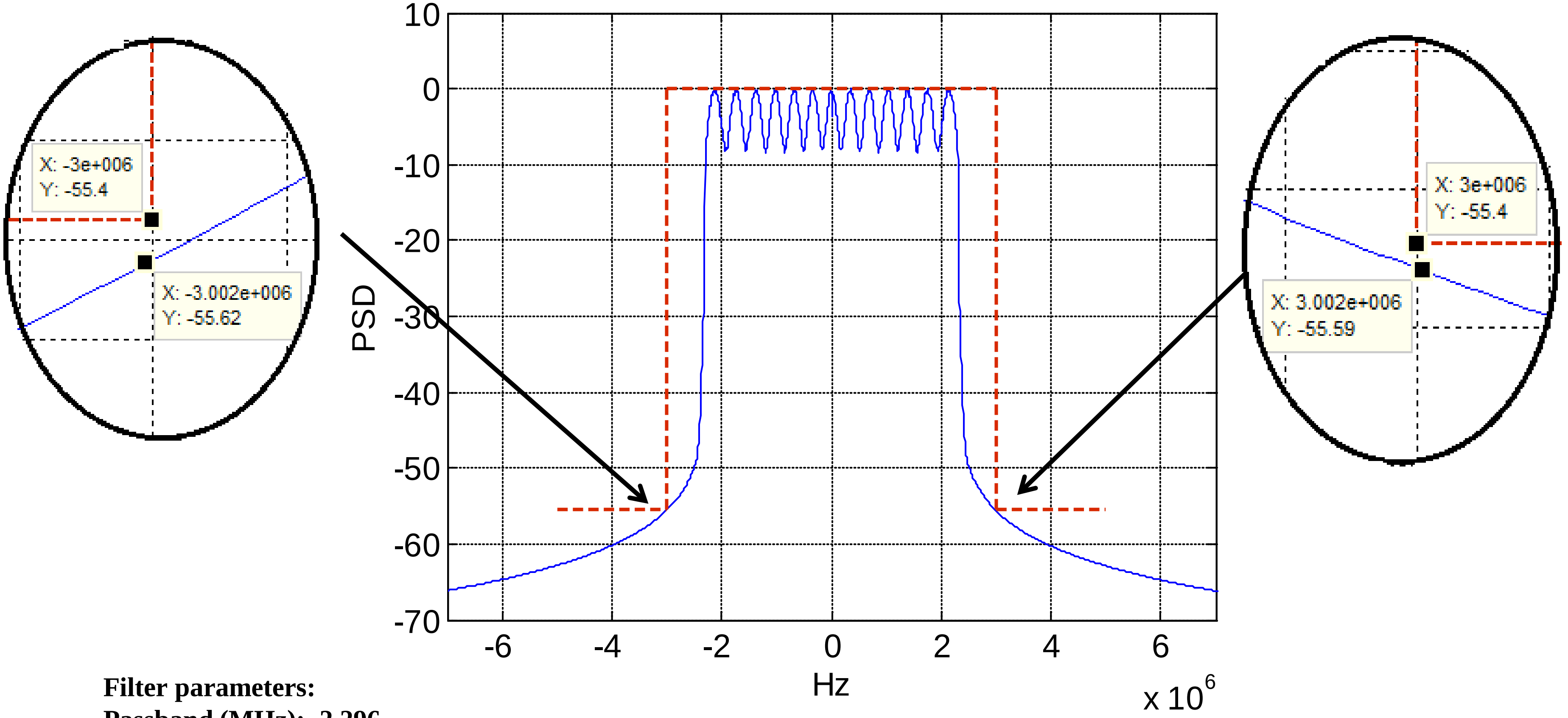
US

Parameters	Value	Notes
Number of DC subcarriers	1	
N_{used}	841	Number of all subcarriers used within a symbol
Guard Subcarriers: left, right	92, 91	–
Tile Permutation	{ 3, 52, 35, 67,94, 13, 80, 6, 34, 45, 43, 68, 84, 66, 7, 37, 71, 89, 55, 101, 27, 60, 51, 14, 21, 17, 93, 72, 95, 73, 81, 24, 103, 86, 39, 29, 56, 62, 70, 64, 23, 22, 54, 15, 90, 76, 100, 3, 36, 18, 9, 91, 19, 26, 12, 92, 48, 25, 87, 74, 5, 31, 85, 40, 104, 2, 102, 69, 57, 50, 1, 44, 0, 20, 88, 79, 16, 28, 46, 42, 41, 59, 96, 97, 99, 82, 30, 49, 65, 77, 63, 11, 8, 75, 98, 38, 32, 83, 4, 47, 58, 61, 78, 10, 53}	Used to allocate tiles to subchannels
$N_{subchannels}$	105	–
N_{tiles}	210	–
Number of subcarriers per tile	4	Number of all subcarriers used within tile
Tiles per subchannel	2	–

Some 22b PHY specs different from 22
-Pilot Pattern-



Spectrum Mask Evaluation

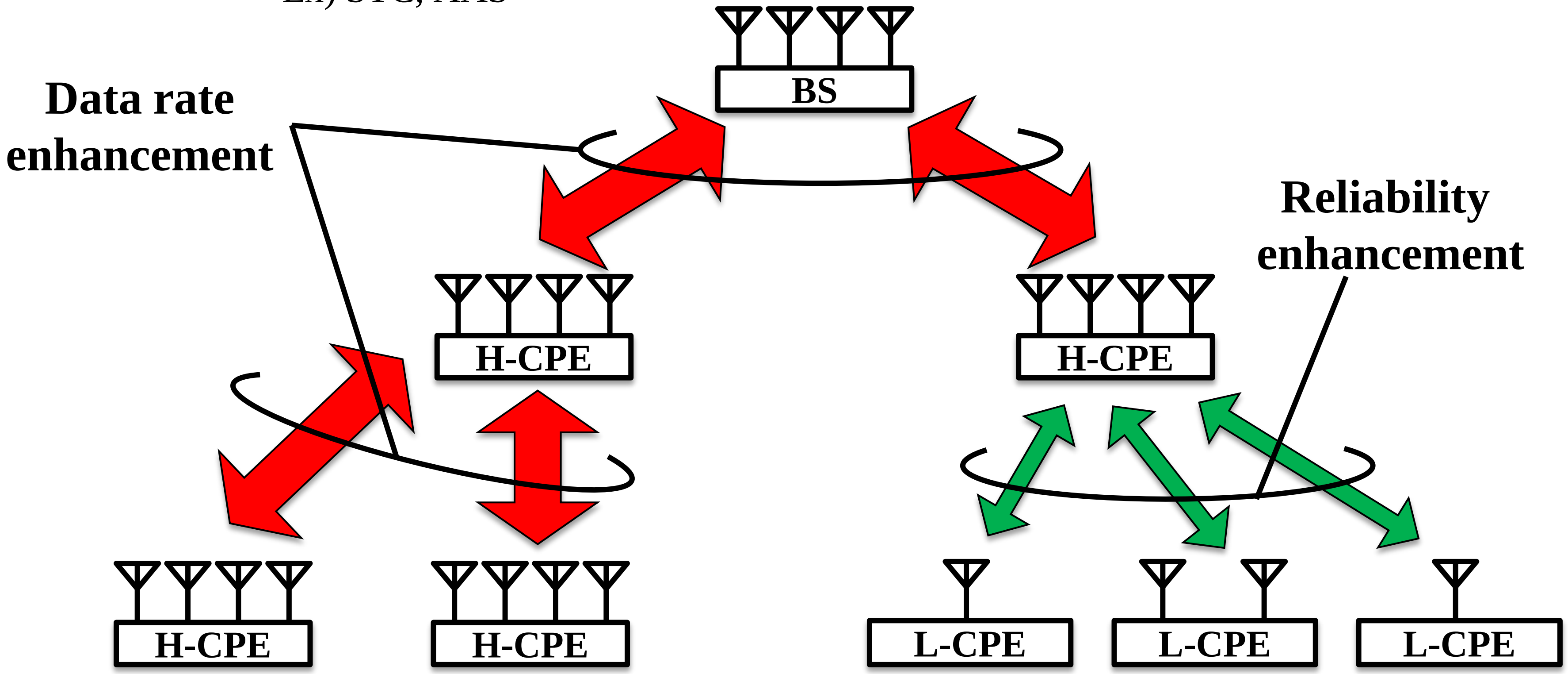


Filter parameters:
Passband (MHz): 2.296
Stopband (MHz): 2.531
Passband atten: 1
Stopband atten: 2500dB
Filter order: 300

Sampling frequency: 5.6MHz

MIMO

- **Usages of multiple antennas**
  - Data rate enhancement (Spatial multiplexing): BS~H-CPE, H-CPE~H-CPE
    - Ex) ZF-MIMO, MMSE-MIMO, SVD-MIMO, Multiuser-MIMO
  - Reliability enhancement (Spatial diversity): BS~L-CPE, H-CPE~L-CPE
    - Ex) STC, AAS



PHY Performance

	802.22	802.22b		
Duplex mode	TDD	TDD		
Multiplex mode	OFDMA	OFDMA		
Channel bandwidth	6	6	MHz	
FFT size	2048	1024	carriers	
Sampling frequency	6.857	5.600	MHz	
Sampling period (time unit: TU)	145.833	178.571	nsec	
Carrier spacing	3.348	5.469	kHz	
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		704.4		US
Upper channel edge guardband	186.7	723.6	kHz	DS
		701.6		US
Frame				
Frame period	10	10	ms	
Frame preamble (2-sequence)	1	1	symbols	
FCH, DS-MAP and US-MAP	1	2	symbols	
Downstream subframe				
DS useful symbols	21	9	symbols	
DS pilot symbol occupation ratio	1/7	1/4	symbols	
DS data carriers per symbol	1440	624	carriers	
Upstream subframe				
US useful symbols	8	39	symbols	
US pilot symbol occupation ratio	1/7	1/7		
US data carriers per symbol	1440	720	carriers	

Adaptive modulation		
Lowest raw efficiency (QPSK)	2	bit/(s*Hz)
(16QAM)	4	bit/(s*Hz)
Highest raw efficiency (64QAM)	6	bit/(s*Hz)
Lowest FEC (1/2)	0.5	
FEC (2/3)	0.667	
FEC (3/4)	0.75	
Highest FEC (5/6)	0.833	

WRAN system throughput		
Maximum raw throughput (802.22) =	28.10	Mbit/s
Maximum raw throughput (802.22b Mode1) =	22.97	Mbit/s
Maximum raw throughput (802.22b Mode2) =	22.86	Mbit/s
Maximum raw throughput (802.22b Mode1 MIMO 4x4) =	**91.88**	Mbit/s
Maximum raw throughput (802.22b Mode2 MIMO 4x4) =	**91.44**	Mbit/s
Maximum net PHY throughput (802.22)=	20.88	Mbit/s
Maximum net PHY throughput (802.22b Mode1)=	16.56	Mbit/s
Maximum net PHY throughput (802.22b Mode1)=	16.85	Mbit/s
Maximum net PHY throughput (802.22b Mode1 MIMO 4x4)=	**66.24**	Mbit/s
Maximum net PHY throughput (802.22b Mode2 MIMO 4x4)=	**67.39**	Mbit/s

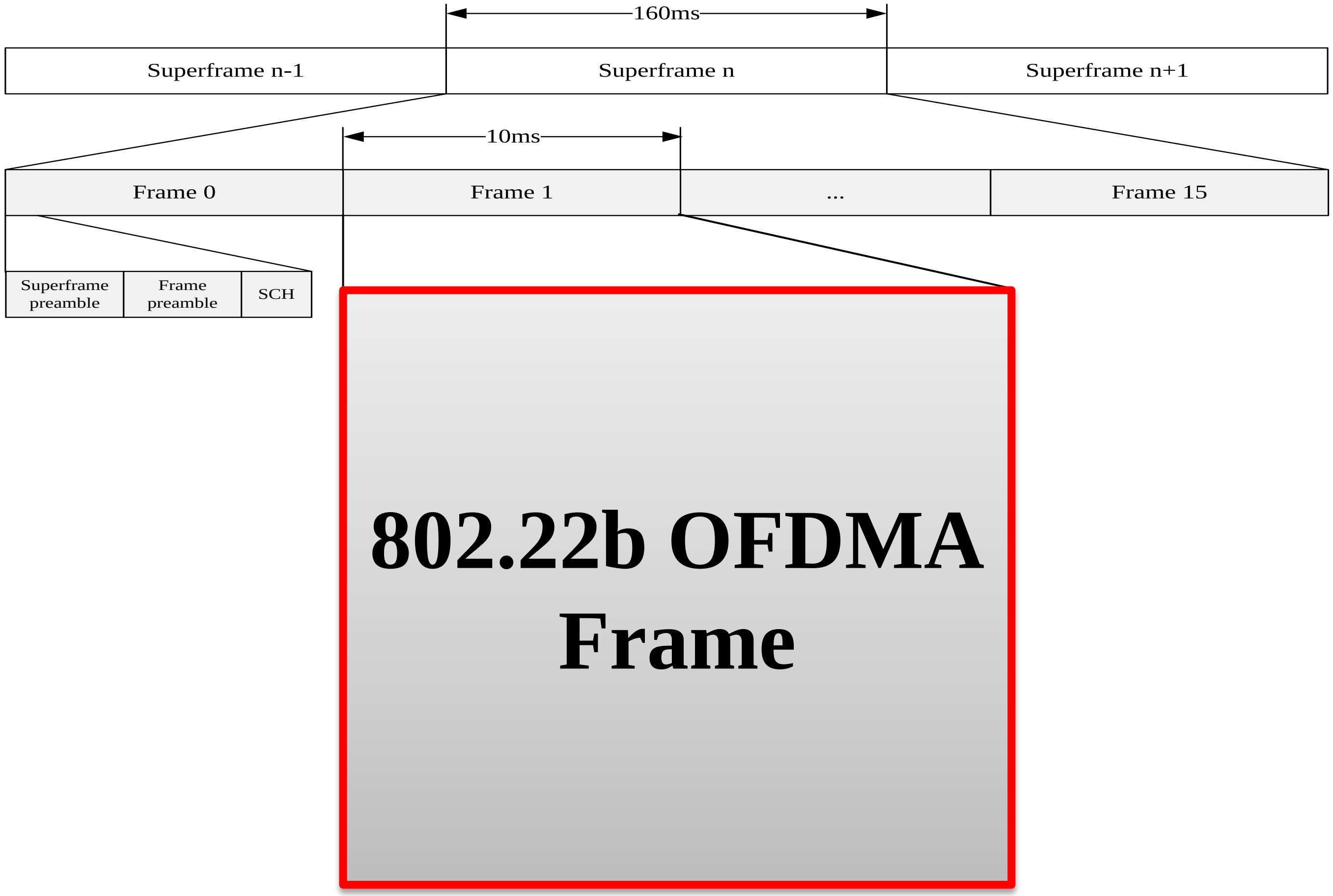
- **Raw throughput: without considering overhead (preamble, header, etc)**
- **Net throughput: with considering overhead (preamble, header, etc)**

802.22b Scope: The standard supports aggregate data rates greater than the maximum data rate supported by the IEEE Std. 802.22-2011.

802.22b Frame Structure

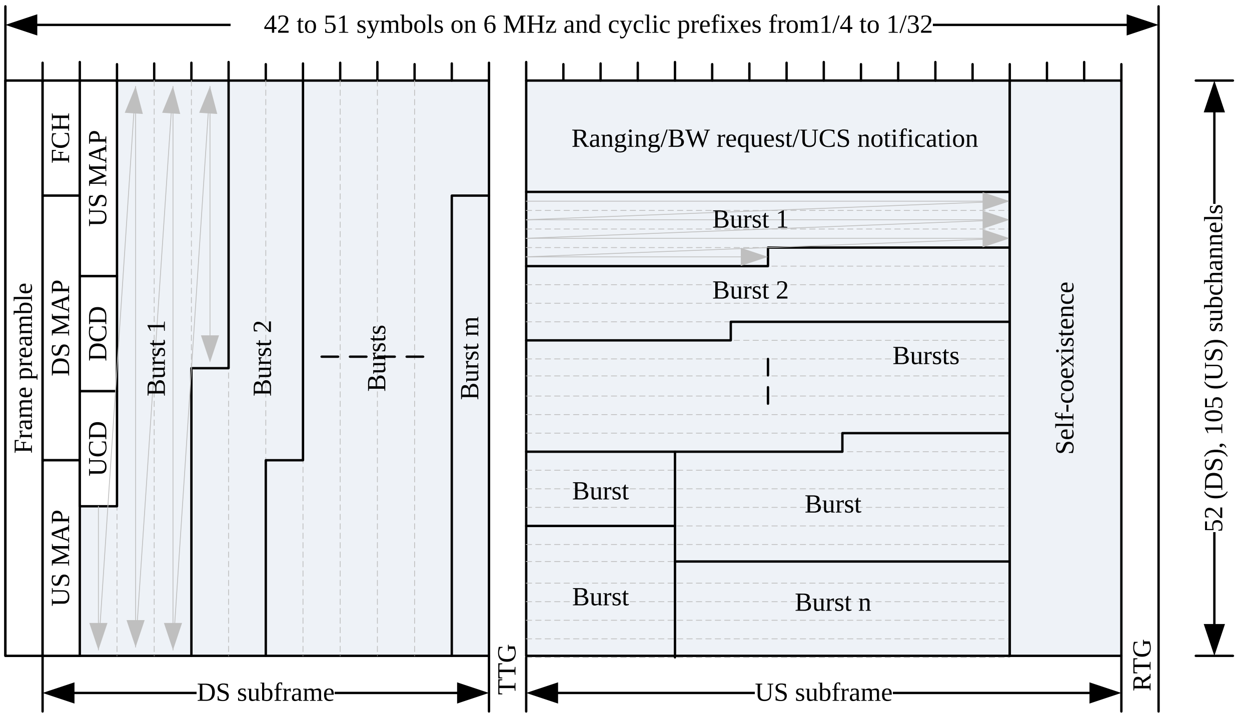
802.22b Frame

- **Same superframe format of 802.22 frame**



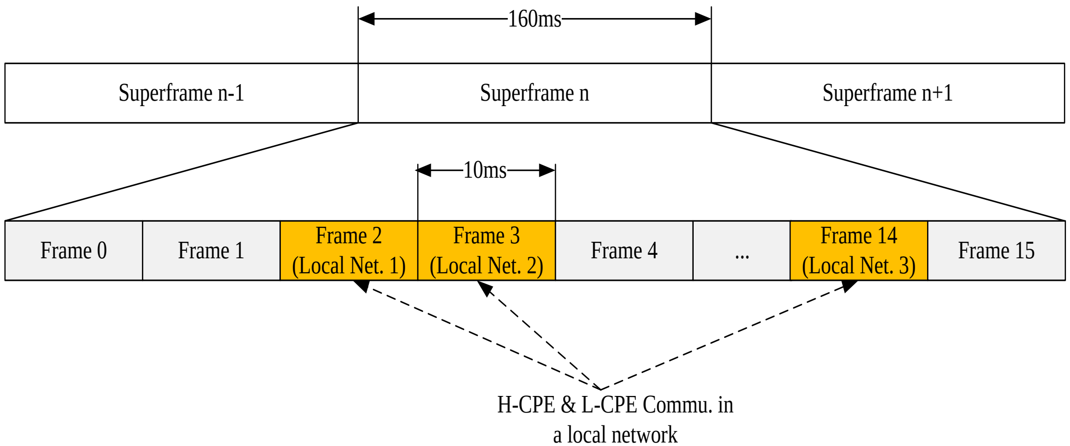
802.22b Frame

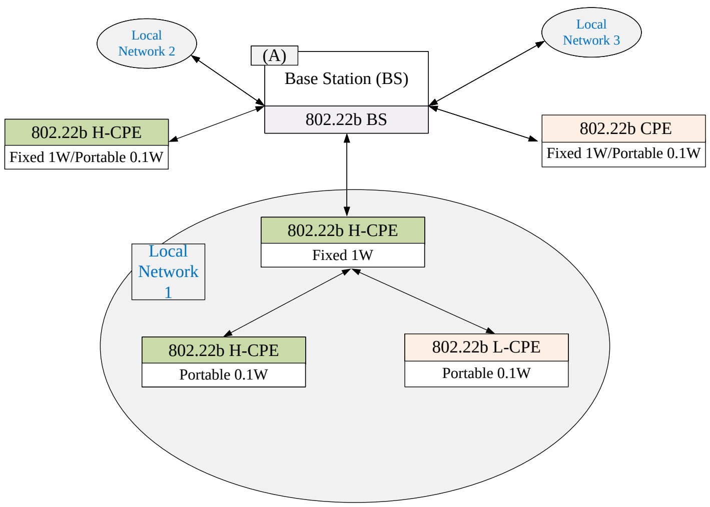
- **802.22b OFDMA Frame Structure**
  - Includes same information of 802.22 OFDMA frame (DS subframe, US subframe, self-coexistence, etc)
  - 42 ~ 51 symbols on 6 MHz (from CP 1/4 to 1/32)
  - 52 (DS), 105 (US) subchannels (see pg. 14, PHY parameters)



802.22b Frame

- **Multi-hop Frame Allocation**
  - More than one Frame into 16 Frames is allocated for a local network
- **To support**
  - Interference avoidance among neighbor local networks
  - Easy control and management
  - Network load balancing

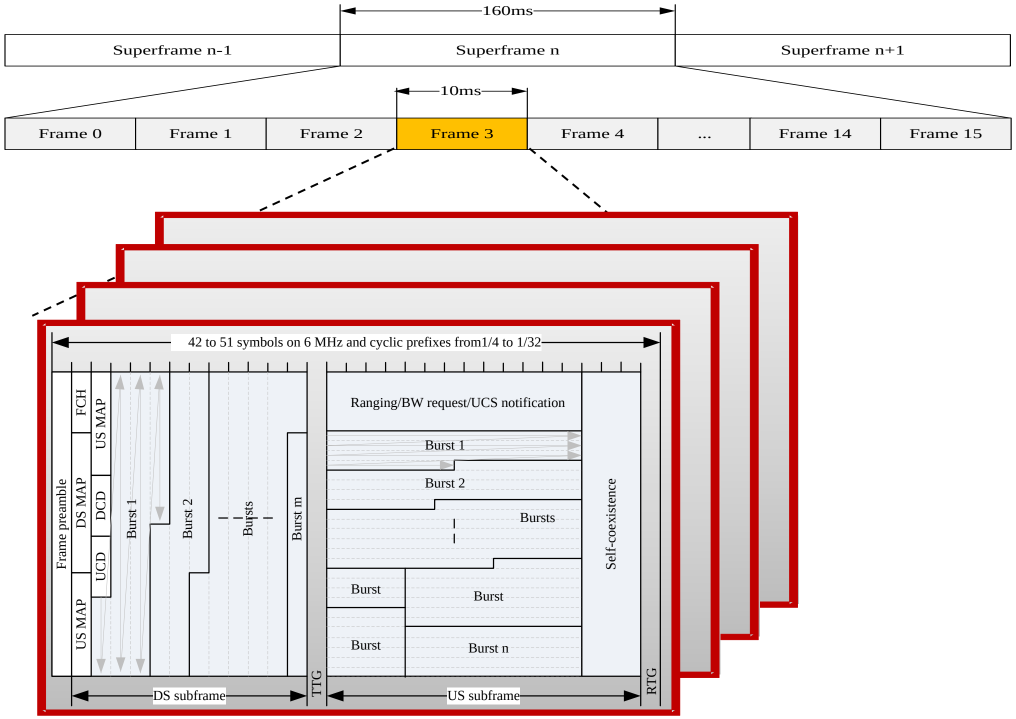




Example of Multi-hop Frame Allocation

802.22b Frame

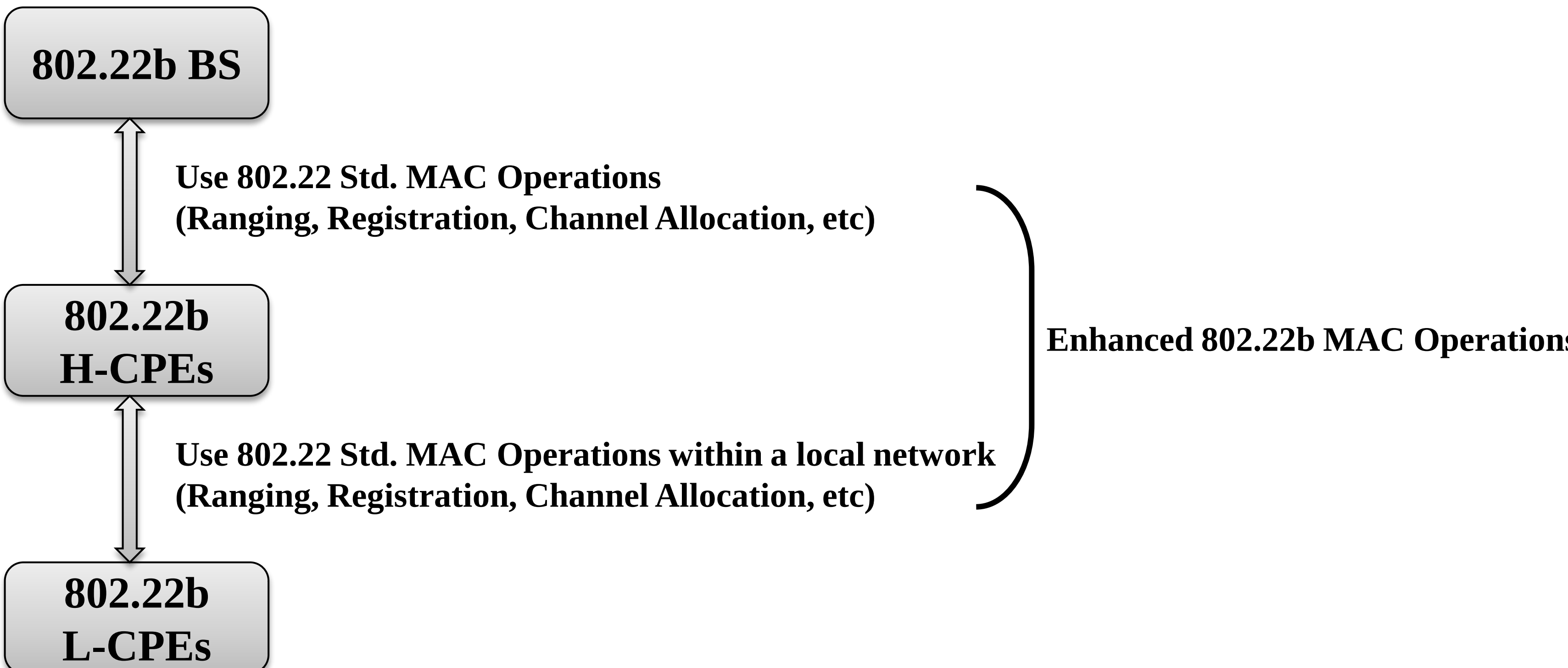
- **Multi-hop Frame Re-use**
  - Reuse multi-hop frame among non-interfering local networks
- **To support**
  - Enhanced network performance
  - Increased network capacity



802.22b MAC

802.22b MAC Operations

- **802.22b MAC operates on the same 802.22 Std. MAC operations, while supports enhanced MAC operations**

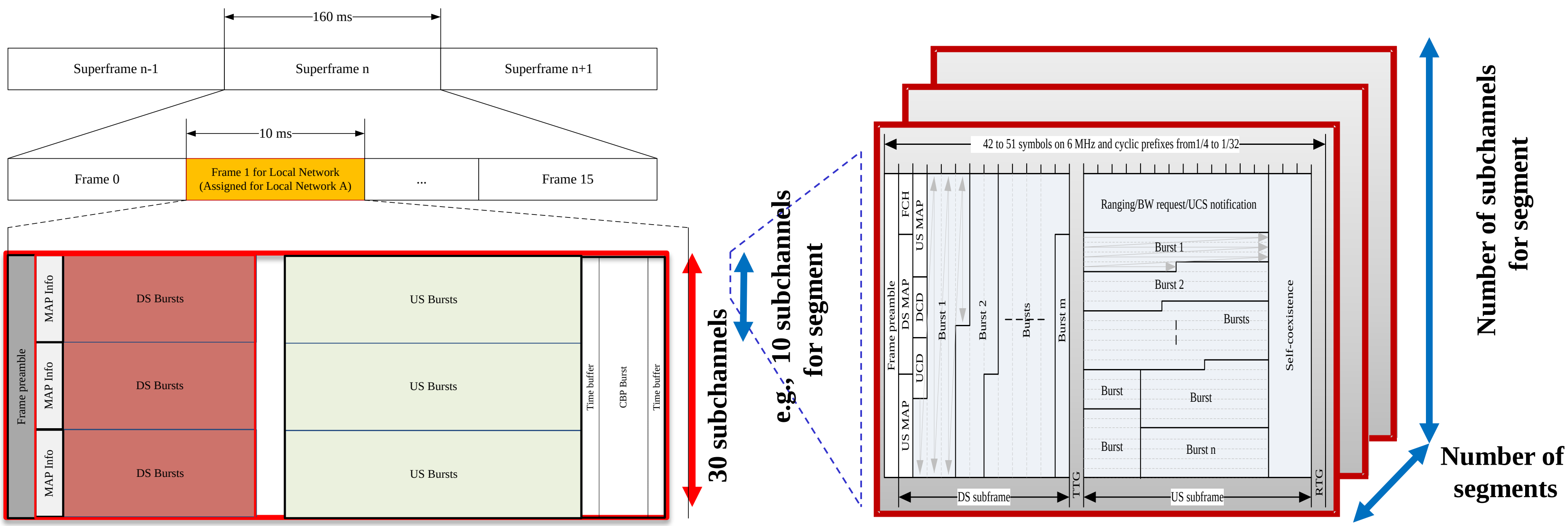


Enhanced MAC

- **Enhanced Channel Utilization**
  - Segment-based OFDMA Frame
  - Multi-hop Frame Relinquish
- **Multi-Channel Utilization**
- **Enhanced Frame Transmission**
  - L2/L3 frame transmission and addressing for multi-hop
- **Functional Handover**
- **MIMO Management**

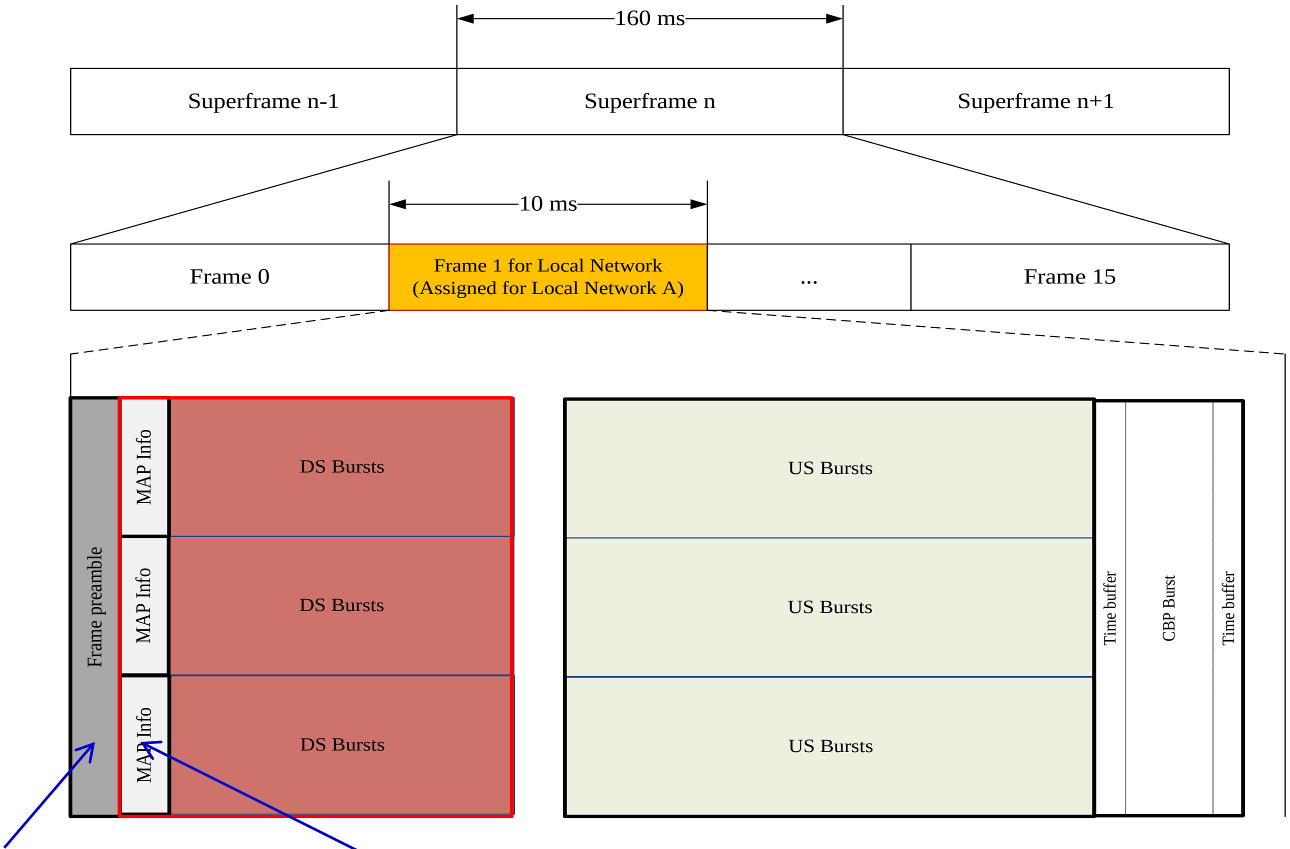
Enhanced Channel Utilization (1/3)

- **Segment-based OFDMA Frame**
  - One OFDMA frame is segmented by a group of sub-channels
- **To support**
  - Increased network capacity
  - Network load balancing
  - Backward compatibility



Enhanced Channel Utilization (2/3)

- **Segment-based OFDMA Frame Format**

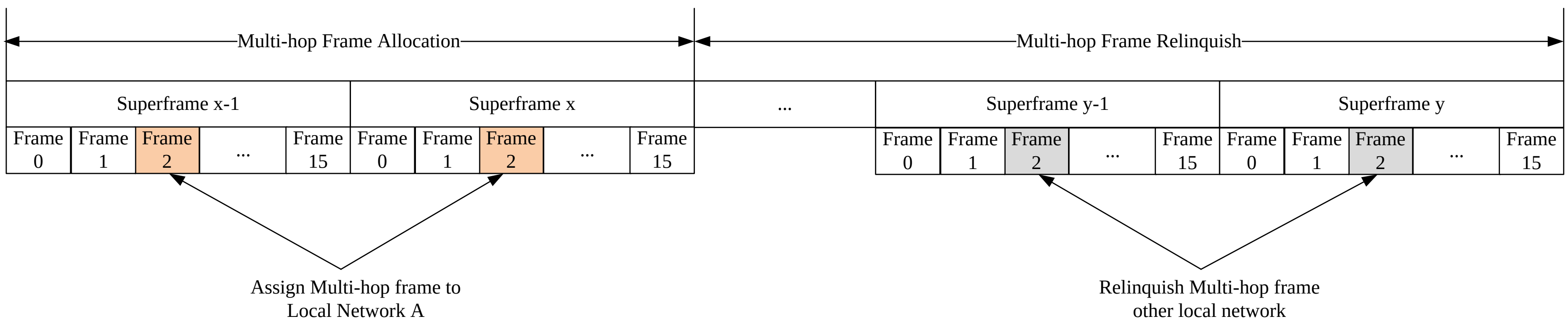


Frame preamble (frame synchronization)

MAP Info (segmented channel detection , segmented channel information)

Enhanced Channel Utilization (3/3)

- **Multi-hop Frame Relinquish**
  - Allocated multi-hop frame can be relinquished to other local network
- **To support**
  - Increased frame utilization
  - Increased network capacity
  - Network load balancing



Multi-Channel Utilization

- **Multi-Channel Utilization**
  - More than one TV channels are aggregated to communicate in a 802.22b network

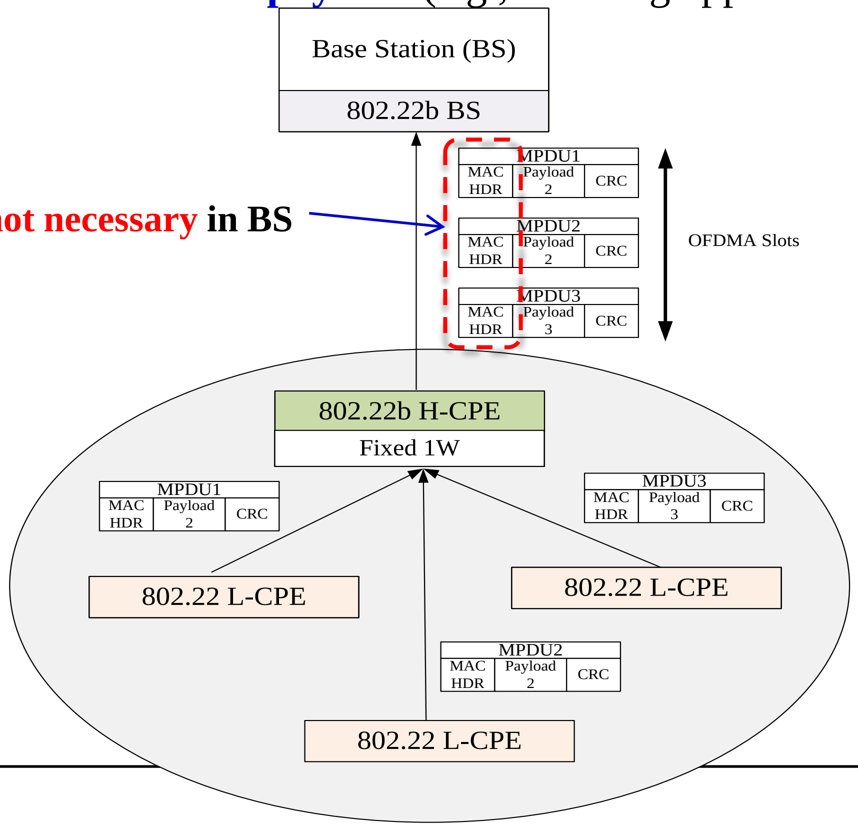
- 802.22 Std. supports transmission of multi-channel information (e.g., operating channel, back-up channel, candidate channel, etc) for cognitive functions, while there is **no multi-channel operations**

- **Multi-Channel Utilization IE / Multi-Channel Operations**
  - is transmitted from BS to 802.22b CPEs
  - contains available TV channels to use in a network
  - indicates multi-channel appearances
  - includes primary channel and secondary channels
    - Primary channel is used for transmit network management signals and data bursts
    - Second channel is used for transmit data bursts

Enhanced Frame Transmission (1/3)

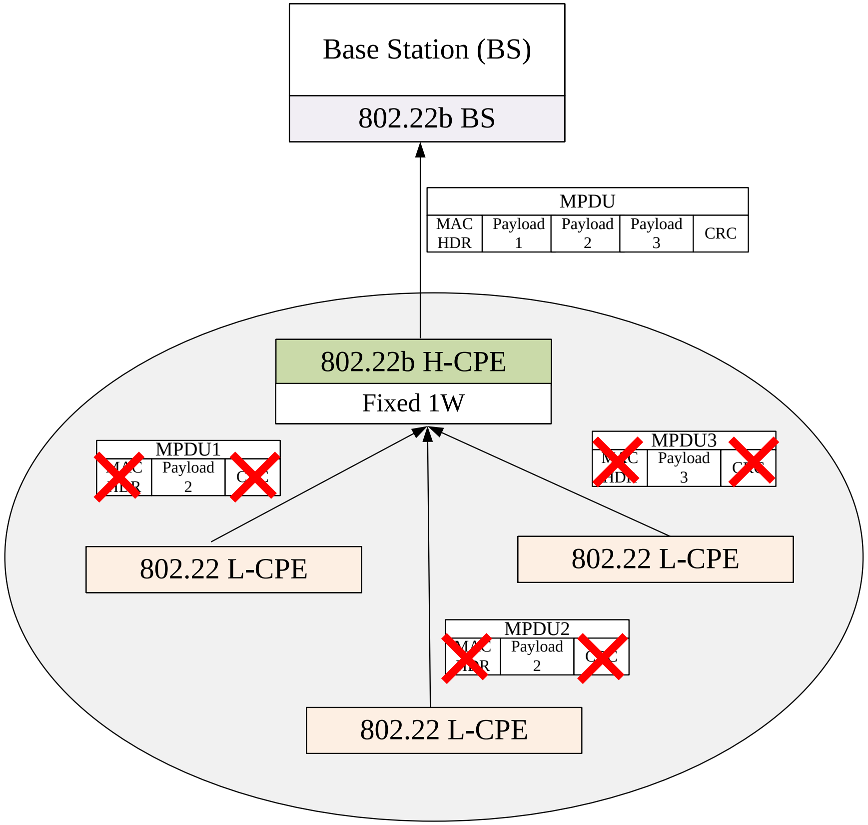
- **Support both L2 & L3 Frame Transmission**
- **L2 uplink on Multi-hop Networks**
  - Relay uplink frame at H-CPE
  - Easy frame management
  - **But, larger overhead on small payload** (e.g., metering applications)

Include information being not necessary in BS



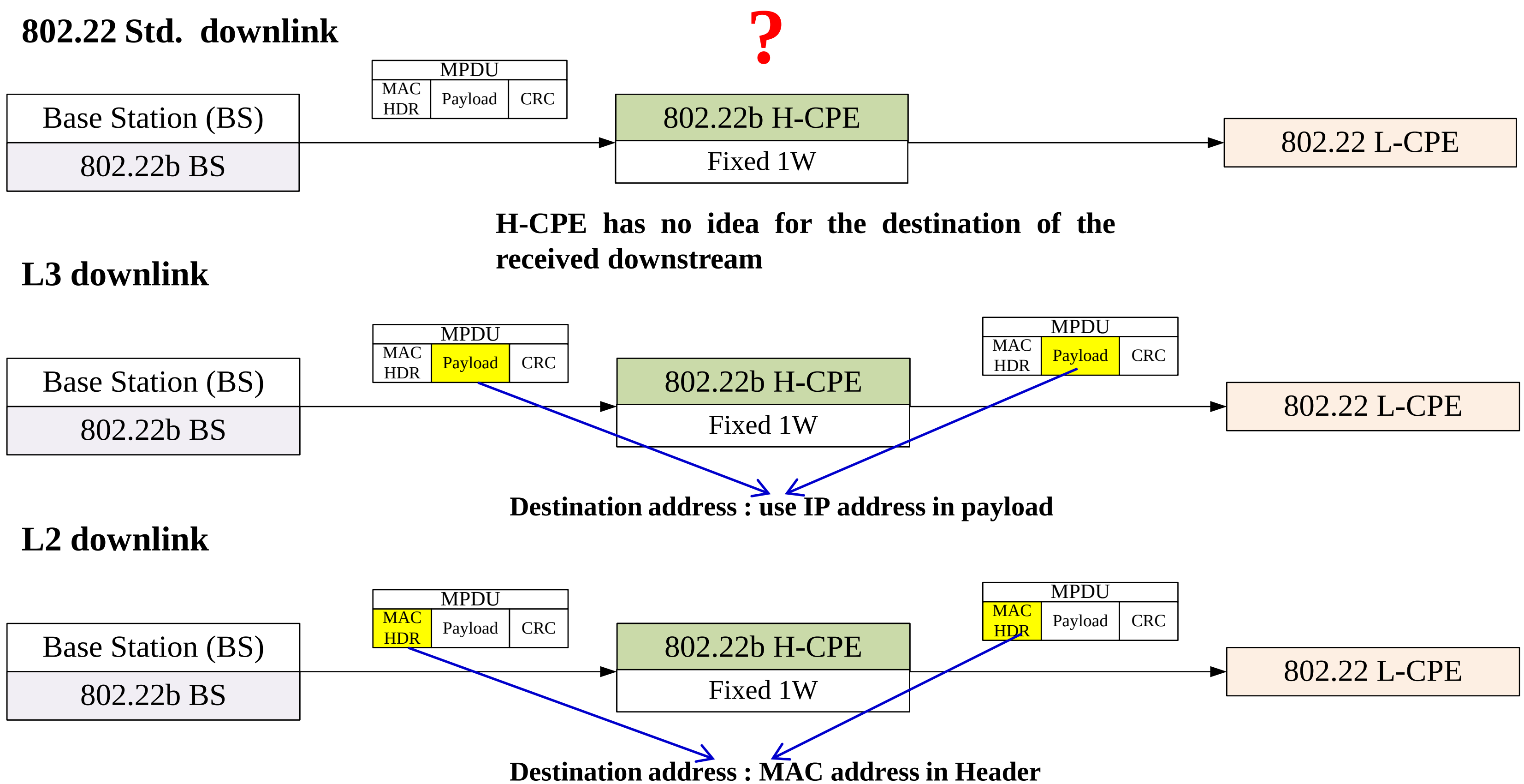
Enhanced Frame Transmission (2/3)

- **L3 uplink on Multi-hop Networks**
  - **Re-construct uplink frame on Layer 3 at H-CPE**
  - **Reduce frame overhead on small payload** (e.g., metering applications)



Enhanced Frame Transmission (3/3)

- **Support both L2/L3 downlink on Multi-hop Networks**
  - 802.22 Std. has no address for destination to route downstream
  - L2/L3 downlink addressing



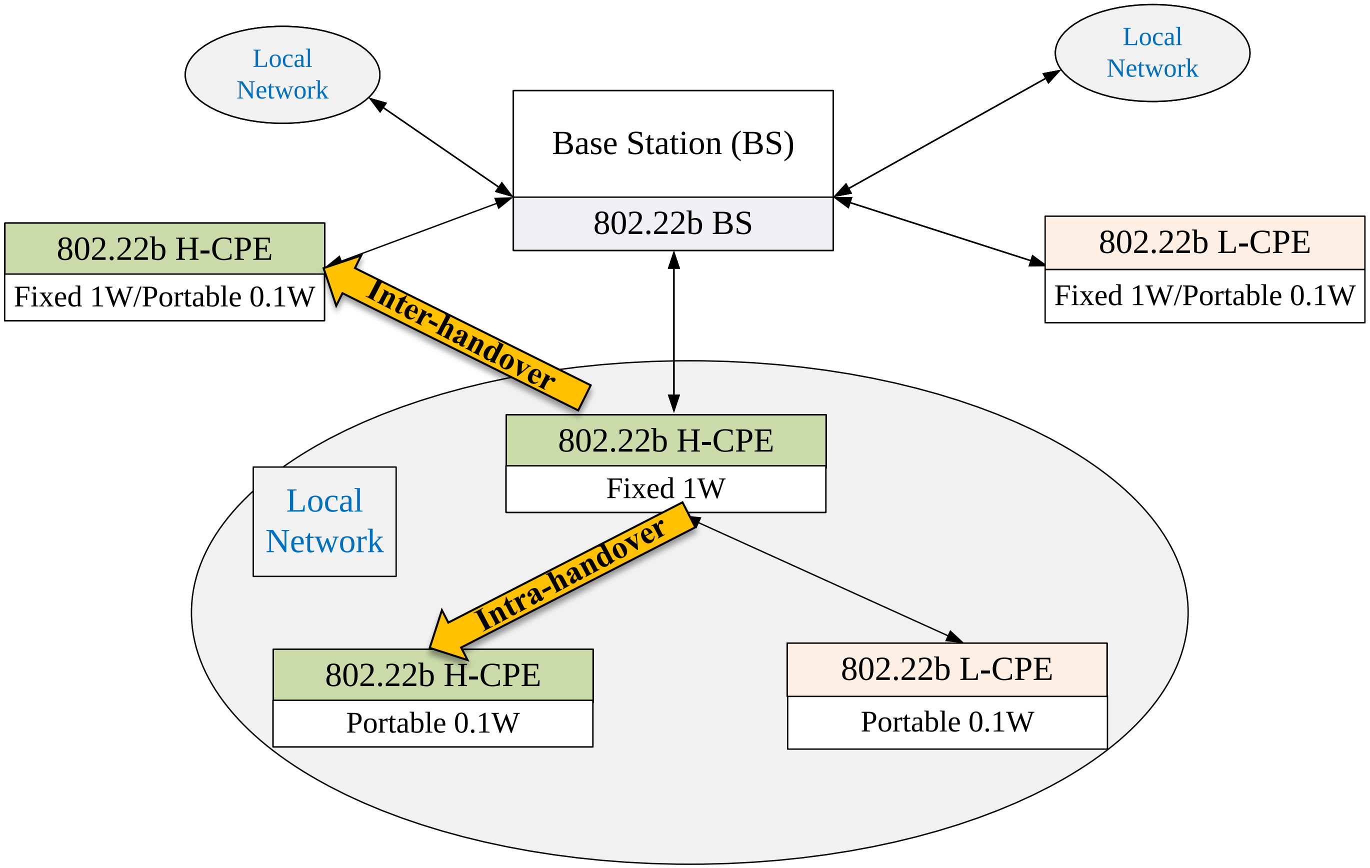
Functional Handover (1/2)

- **Functional Handover**
  - When combining or dividing a local network, or removing Parent H-CPE from a local network, transferring Parent H-CPE function to neighbor Parent H-CPE or Child H-CPE with capability of Parent H-CPE

- **To support**
  - Fast network re-configuration
  - Network load balancing

- **Functional handover Types**
  - Intra-handover
    - Performing handover to Child H-CPE with capability of Parent H-CPE within the same local network
  - Inter-handover
    - Performing handover to the neighbor Parent H-CPE

Functional Handover (2/2)

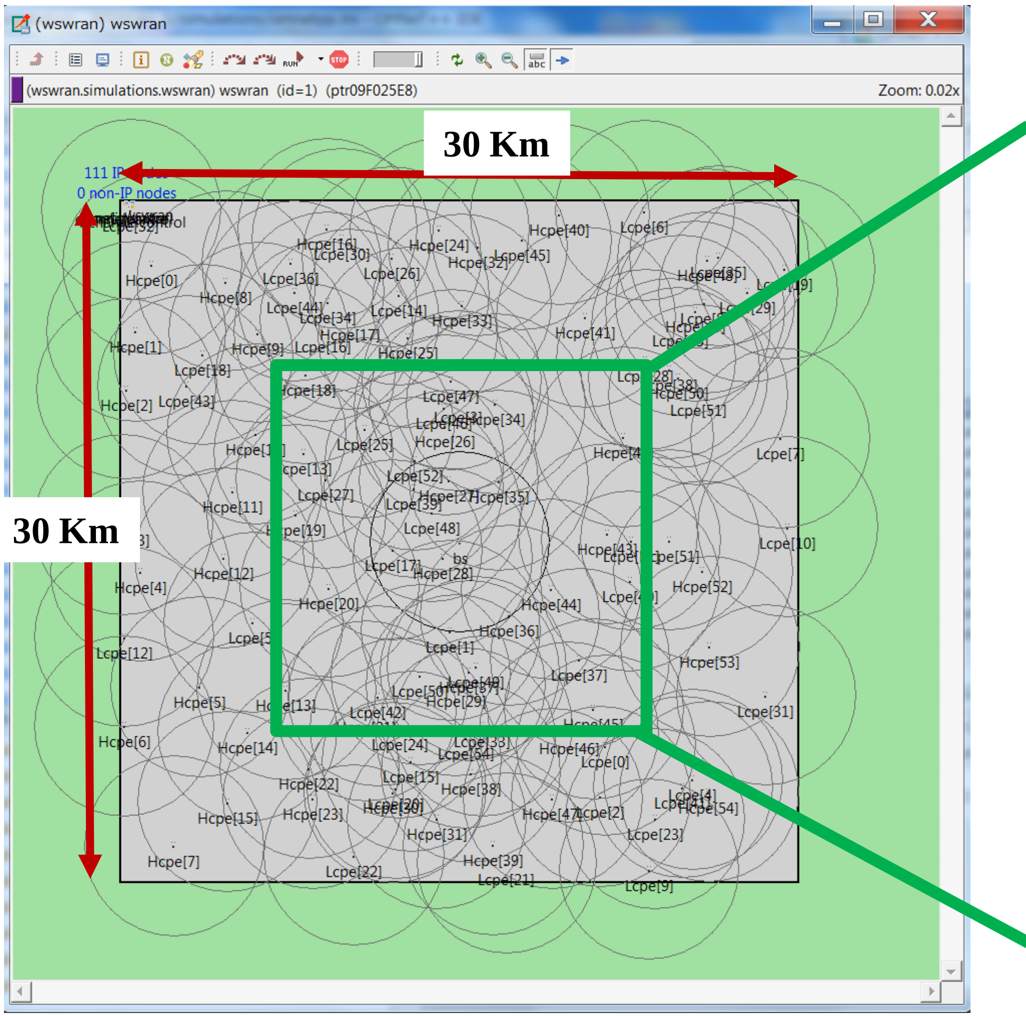


MIMO Management

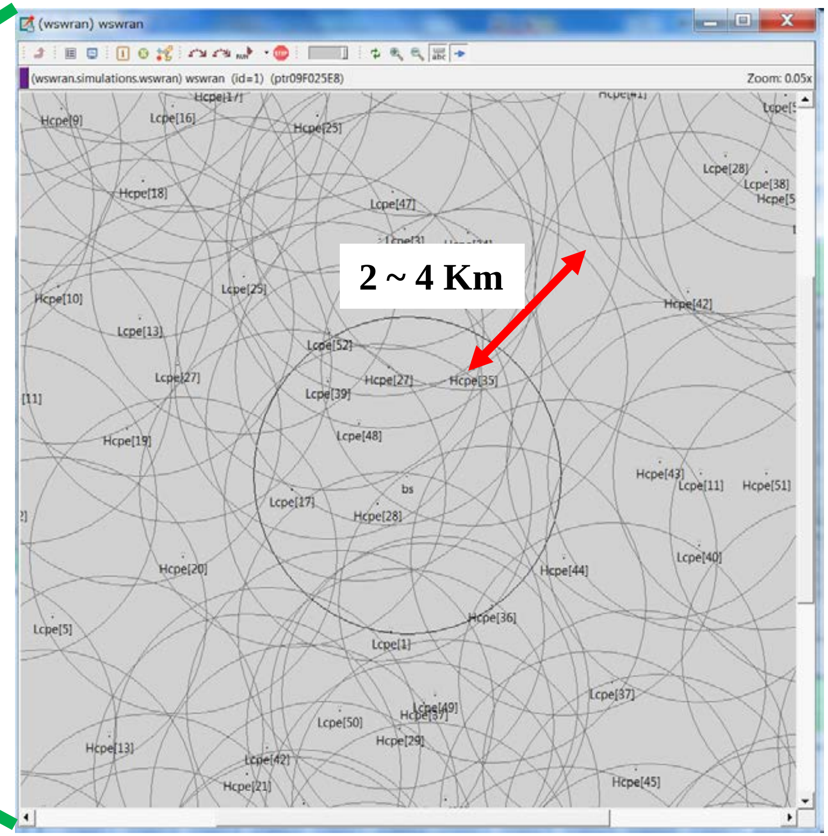
- **MIMO Management**
  - TBD

802.22b Performance

802.22b Network Simulation

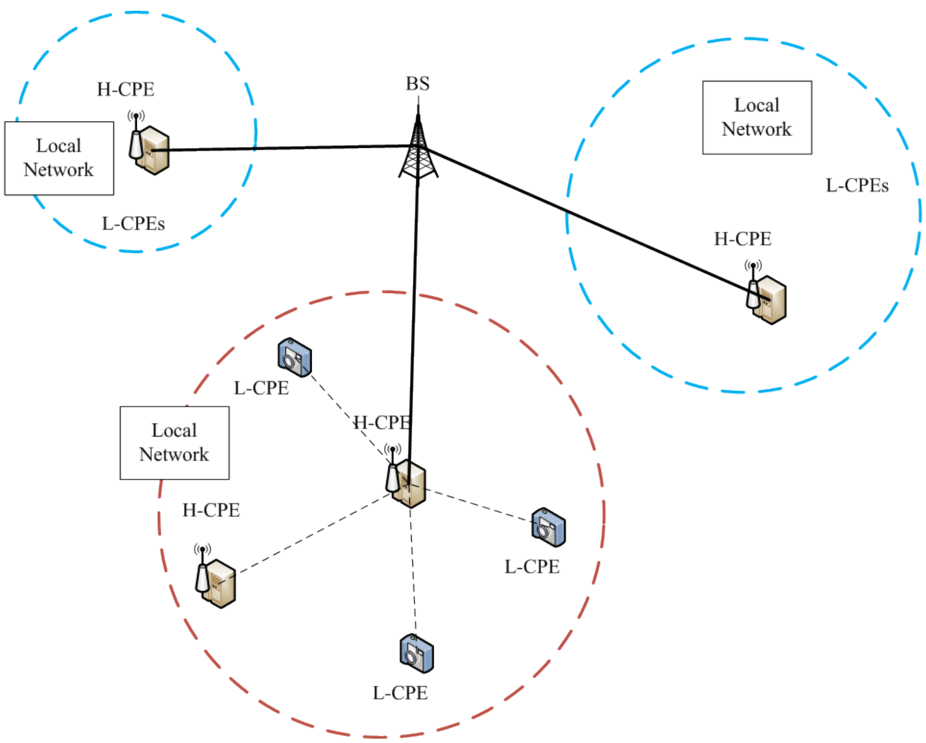


- BS coverage: 30Km
- Local network coverage (managed by H-CPE): 2~4Km



Simulator (Omnet++ 4.2)

Network Capacity

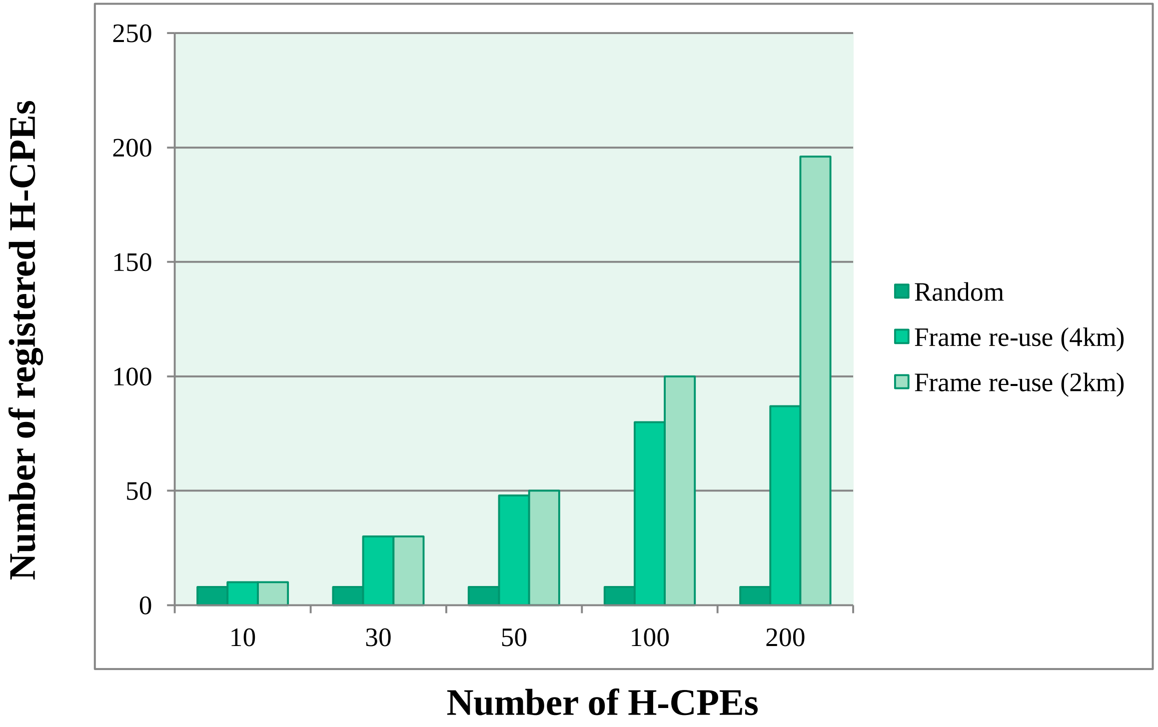


Example of 802.22b Network

- **Network Capacity**
  - Number of devices (H-CPEs and L-CPEs) registered at BS
- **Average Network Capacity =**
  - Average number of registered H-CPEs x Average number of L-CPEs per H-CPEs
- To increase network capacity, it prefers to increase the number of registered H-CPEs

Network Capacity

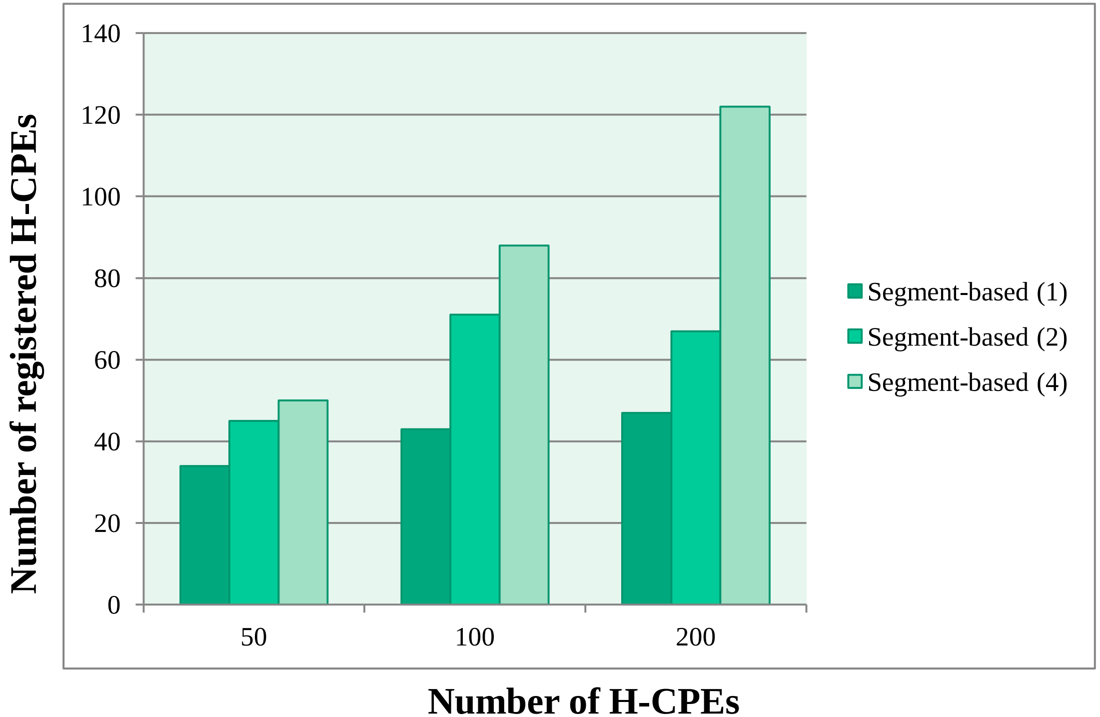
- **Frame Allocation (Random vs. Frame re-use)**
  - 2Km (and) 4Km range for a local network
  - 8 Frames are used for BS↔H-CPE, other 8 Frames are used for H-CPE↔L-CPEs



Frame re-use is able to highly increase network capacity, specially, on the small range of a local network

Network Capacity

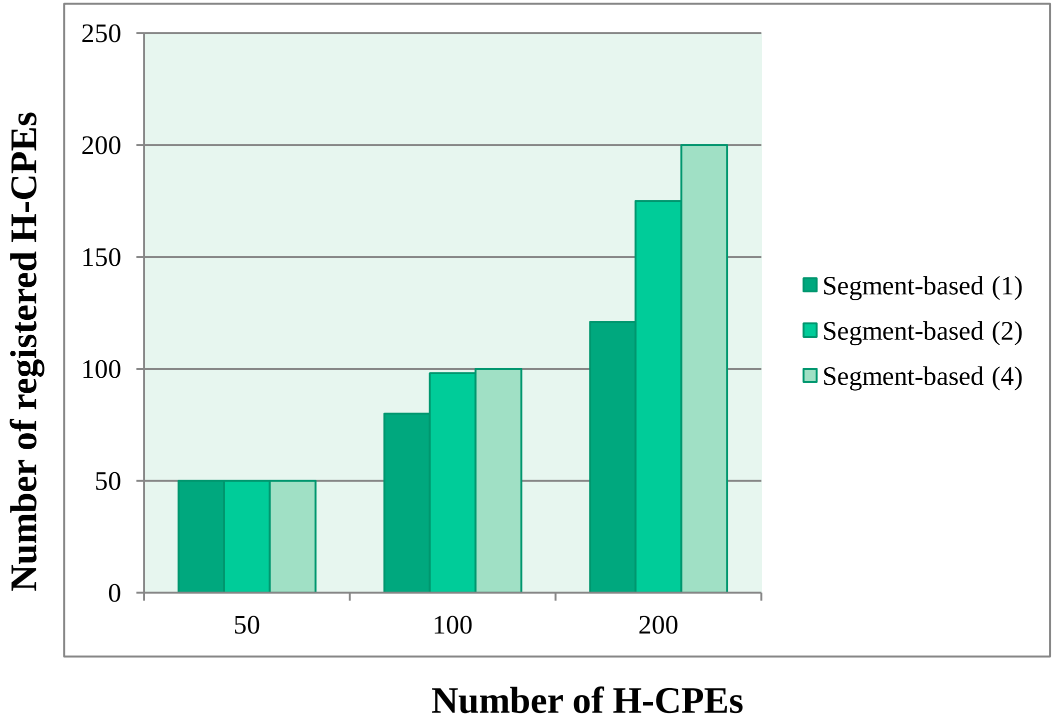
- **Segment-based OFDMA**
  - **4Km** range for a local network
  - 12 Frames are used for BS↔H-CPE, other 4 Frames are used for H-CPE↔L-CPEs
  - Number of segments: 1, 2 and 4



Segment-based OFDMA is able to highly increase network capacity

Network Capacity

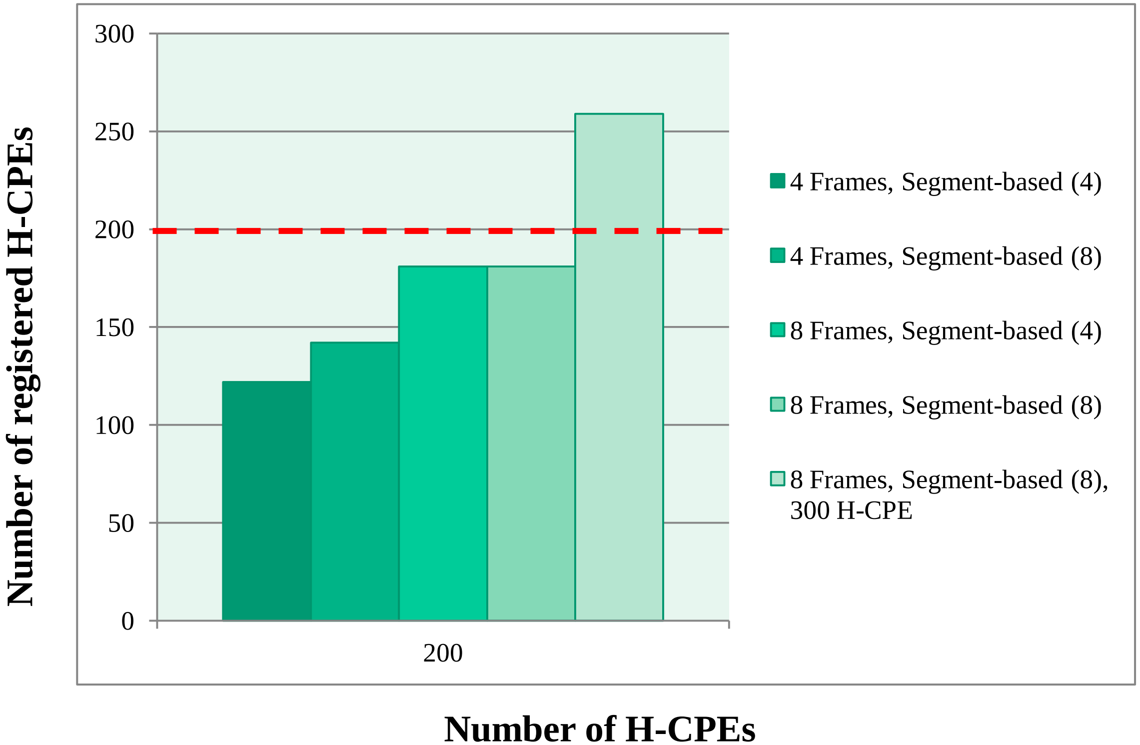
- **Segment-based OFDMA**
  - **2Km** range for a local network
  - 12 Frames are used for BS↔H-CPE, other 4 Frames are used for H-CPE↔ L-CPEs
  - Number of segments: 1, 2 and 4



Segment-based OFDMA is able to highly increase network capacity, specially, on the small range of a local network

Network Capacity

- **Re-used frames and Segments Decision**
  - Required capacity
    - 4Km range for a local network
    - 200 H-CPEs



Three methods of **frame re-use**, **segment-based OFDMA** and **Power management** should be used for supporting a large network

Network Performance

- **Throughput, Delay and Packet Error Rate**
  - Will be updated (TBD)

Proposal Summary (Network)

Proposals				Main Properties
General	802.22b Network	802.22b Device Classes	802.22b BS	• MIMO Support • Channel Aggregation Support •Management of a whole 802.22b network • 1K FFT
			802.22b H-CPE	• Multi-hop (relay) Support • MIMO Support • Channel Aggregation Support • Management of 802.22b L-CPEs • 1K FFT
			802.22b L-CPE	• 1K FFT
		Network Configuration	Direct Connection	CPEs can communicates with BS directly
			Multi-hop Connection	Maximum 2-hops from BS to end CPEs
			Local Network	A sub-network managed by 802.22b H-CPE, which contains more than one 802.22b L-CPEs
	802.22b OFDMA Frame	802.22 Std. OFDMA Frame Format		Use 802.22 OFDMA Frame Format and minimum modification related to PHY
		Multi-hop Frame Allocation		Allocated Frames into 16 Frames for a local network
		Multi-hop Frame Re-use		Enhance network performance and capacity

Proposal Summary (PHY)

	802.22b		
Duplex mode	TDD		
Multiplex mode	OFDMA		
Channel bandwidth	6	MHz	
FFT size	1024	carriers	
Sampling frequency	5.600	MHz	
Sampling period (time unit: TU)	178.571	usec	
Carrier spacing	5.469	kHz	
Useful symbol period	182.857	usec	
Cyclic prefix (1/32)	5.714	usec	
Total symbol period	188.571	usec	
Number of null carriers (L, DC, R)	192	carriers	DS
	184		US
Number of used carriers	832	carriers	DS
	840		US
Occupied bandwidth	4.55	MHz	DS
	4.594		US
Lower channel edge guardband	726.4	kHz	DS
	704.4		US
Upper channel edge guardband	723.6	kHz	DS
	701.6		US
Frame			
Frame period	10	ms	
Frame preamble (2-sequence)	1	symbols	
FCH, DS-MAP and US-MAP	2	symbols	
Downstream subframe			
DS useful symbols	9	symbols	
DS pilot symbol occupation ratio	1/4	symbols	
DS data carriers per symbol	624	carriers	
Upstream subframe			
US useful symbols	39	symbols	
US pilot symbol occupation ratio	1/7		
US data carriers per symbol	720	carriers	

WRAN system throughput		
Maximum raw throughput (802.22) =	28.10	Mbit/s
Maximum raw throughput (802.22b Mode1) =	22.97	Mbit/s
Maximum raw throughput (802.22b Mode2) =	22.86	Mbit/s
Maximum raw throughput (802.22b Mode1 MIMO 4x4) =	**91.88**	Mbit/s
Maximum raw throughput (802.22b Mode2 MIMO 4x4) =	**91.44**	Mbit/s
Maximum net PHY throughput (802.22)=	20.88	Mbit/s
Maximum net PHY throughput (802.22b Mode1)=	16.56	Mbit/s
Maximum net PHY throughput (802.22b Mode1)=	16.85	Mbit/s
Maximum net PHY throughput (802.22b Mode1 MIMO 4x4)=	**66.24**	Mbit/s
Maximum net PHY throughput (802.22b Mode2 MIMO 4x4)=	**67.39**	Mbit/s

Proposal Summary (MAC)

Proposals				Properties
MAC	Operation	BS	H-CPEs	Use 802.22 Std. Operations (Ranging, Registration, Channel allocation, etc)
		H-CPE	L-CPEs	Use 802.22 Std. Operations (Ranging, Registration, Channel allocation, etc)
	Enhance MAC	Segmented OFDMA Frame Allocation		Increase network capacity and load balancing
		Multi-hop Frame Relinquish		Increase network capacity
		Multi-channel Utilization		Support multi-channel utilization for channel aggregation
		Enhanced Frame Transmission		Reduce frame transmission overhead
		Multi-hop Addressing		Addressing destination on a multi-hop network
		Functional Handover		Fast network re-configuration and load balancing
		MIMO Management		MAC management for MIMO

Annex: PAR

- **This amendment specifies alternate Physical Layer (PHY) and necessary Medium Access Control Layer (MAC) enhancements to IEEE std. 802.22-2011 for operation in Very High Frequency (VHF)/ Ultra High Frequency (UHF) TV broadcast bands between 54 MHz and 862 MHz to support enhanced broadband services and monitoring applications. The standard supports aggregate data rates greater than the maximum data rate supported by the IEEE Std. 802.22-2011. This standard defines new classes of 802.22 devices to address these applications and supports more than 512 devices in a network. This standard also specifies techniques to enhance communications among the devices and makes necessary amendments to the cognitive, security & parameters and connection management clauses. This amendment supports mechanisms to enable coexistence with other 802 systems in the same band.**

doc.: IEEE 802.22-1/118r04-rasg

Annex: Requirements

- **[Req01] This amendment should provide mechanisms to meet the regulatory requirements. e.g, FCC, Ofcom, etc.**
- **[Req02] This amendment shall provide a means of achieving aggregated throughput at least 2 times higher than the maximum throughput supported by the IEEE Std. 802.22-2011, e.g., Higher Modulation and Coding Scheme (MCS), MIMO, MISO, channel aggregation, etc.**
- **[Req03] This amendment shall define at least two new classes of CPEs to effectively support different service applications of broadband services and monitoring applications. One class of CPE shall be designed with low complexity to fit for monitoring applications.**
- **[Req04] This amendment should provide mechanisms of energy efficient operations, e.g. Battery operated CPEs for monitoring applications.**
- **[Req05] This amendment shall support at least 2048 CPEs to cover a regional area network in some monitoring applications. For example, regional area smart grid/metering needs several thousands of L-CPEs.**
- **[Req06] This amendment should support multi-hop connections within an WRAN network.**
- **[Req07] This amendment may support peer-to-peer communications between CPEs controlled by BS.**
- **[Req08] This amendment should support QoS mechanisms for real-time monitoring applications.**
- **[Req09] This amendment should support mechanisms to coexist with IEEE 802 other systems in the same band.**
- **[Req10] This amendment may provide enhancement to existing or alternate security mechanisms. This amendment should provide authentication and integrity check security mechanisms for peer-to-peer communication.**
- **[Req11] This amendment should support backward compatibility, for example IEEE 802.22-2011 CPEs are able to communicate to IEEE 802.22b BS.**
- **[Req12] This amendment should provide a means for alternative channelization. This amendment should provide methods for cost-effective compliance with regulatory spectral mask.**

doc.: IEEE 802.22-12/0012r03-000b