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

**Submission Title:** [Samsung VLC MAC proposal]

**Date Submitted:** [22 September, 2009]

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**Re:** []

**Abstract:** [Initial proposal for VLC MAC for IEEE 802.15.7 standardization]

**Purpose:** [Contribution to IEEE 802.15.7 VLC TG]

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# Outline

Applications

Frame structure

Frame types

Access mechanisms

MAC header

Visibility support

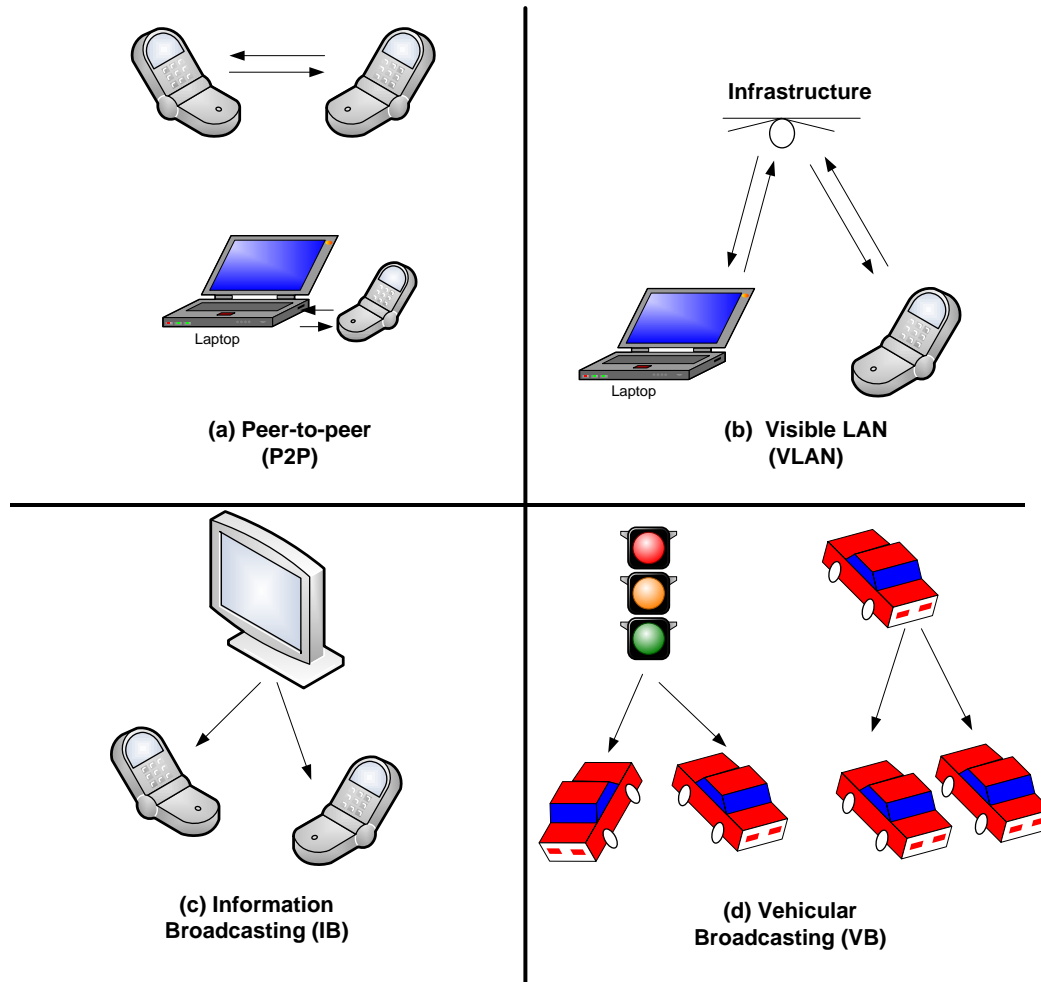
Channel selection and association

Multiple color channel support

Mobility support for handoff

Other MAC features

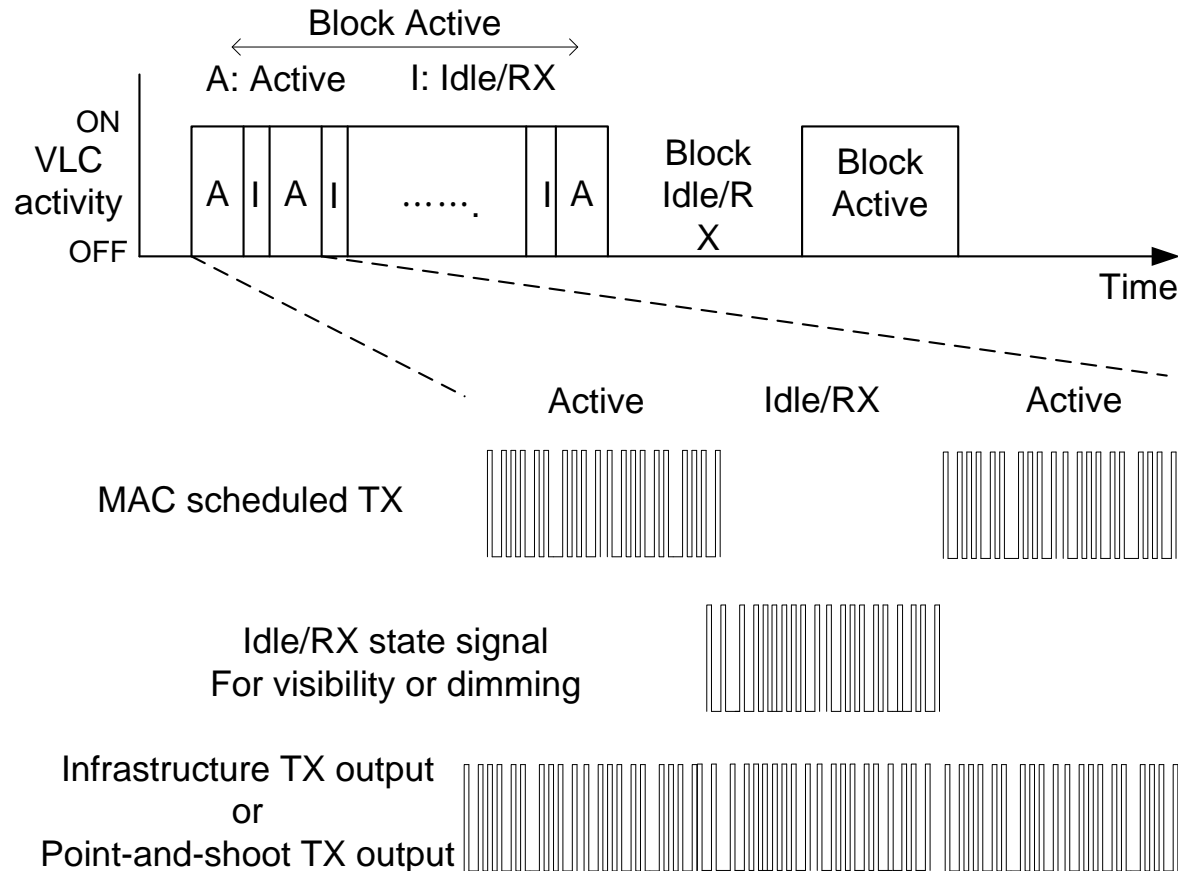
# Applications considered for VLC MAC



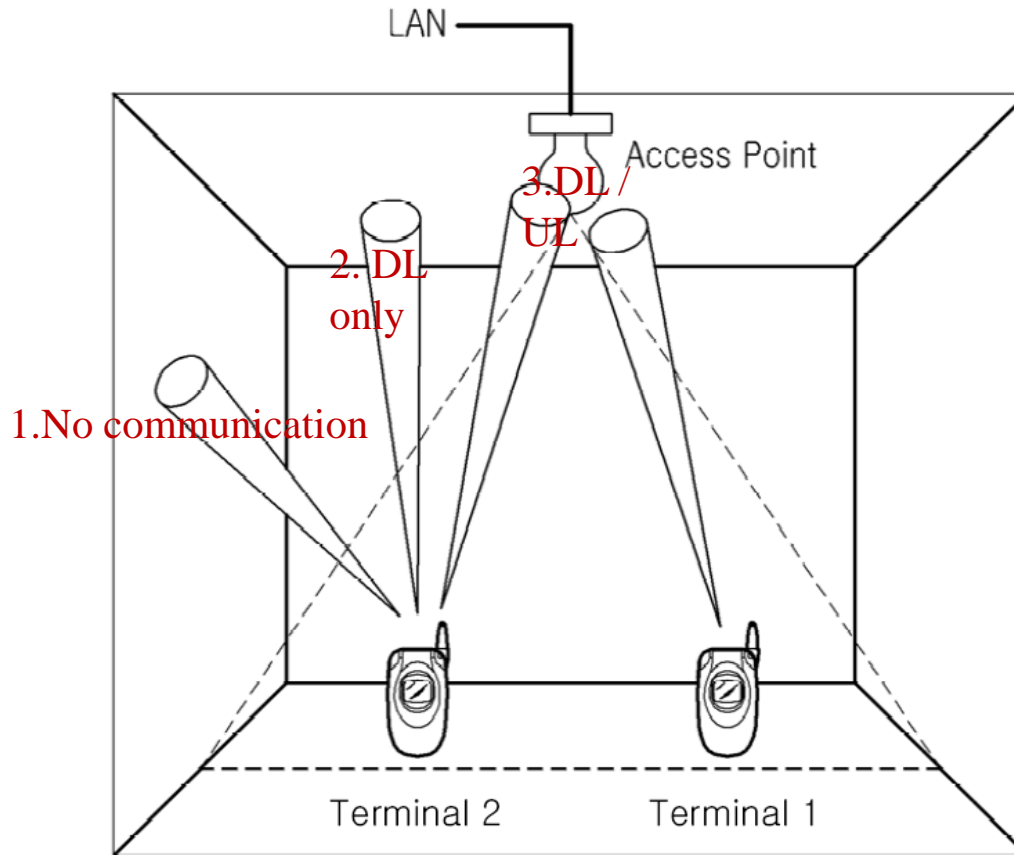
# VLC device classification

	<b>Infrastructure</b>	<b>Mobile</b>	<b>Vehicle-mounted</b>
<b>Fixed access point</b>	Yes	No	No
<b>Power supply</b>	Ample	Limited	Moderate
<b>Form factor</b>	Unconstrained	Constrained	Unconstrained
<b>Light source</b>	Intense	Weak	Intense
<b>Physical Mobility</b>	No	Yes	Yes
<b>Range</b>	Short/long	Short	Long
<b>Data rates</b>	High/Low	High	Low

# Unique requirements for VLC (Infrastructure support)



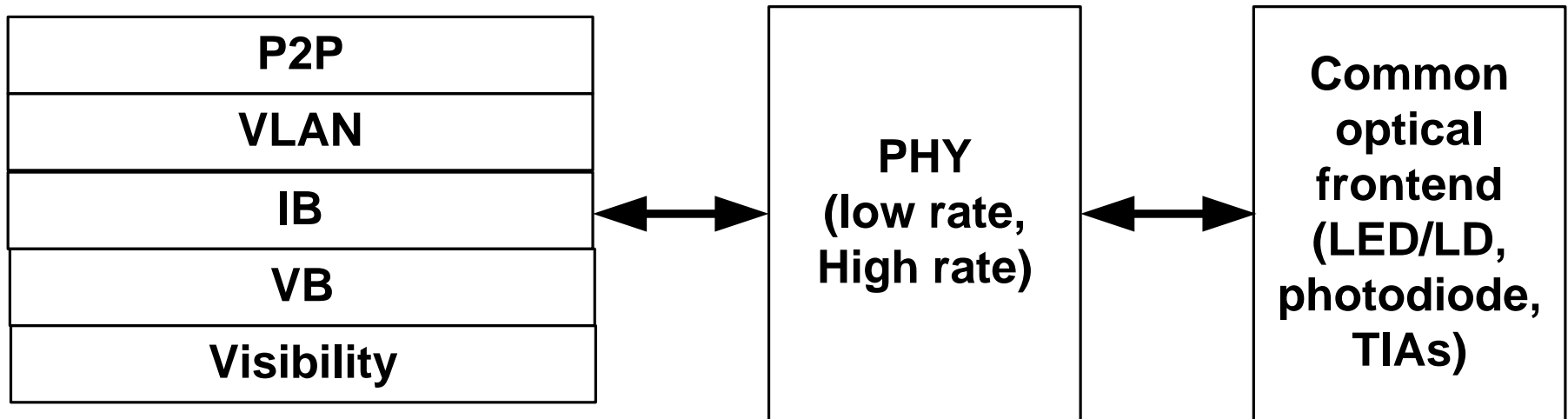
# Unique requirements for VLC (Point-and-shoot for mobile)



Reference: W.C. Kim et al., "Efficient resource allocation scheme for visible-light communication", Proc. Of SPIE, Vol. 7234, pp. 72340M-72340M-9, 2009.

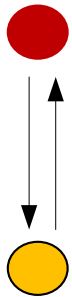
# Single MAC design

## MAC application modes



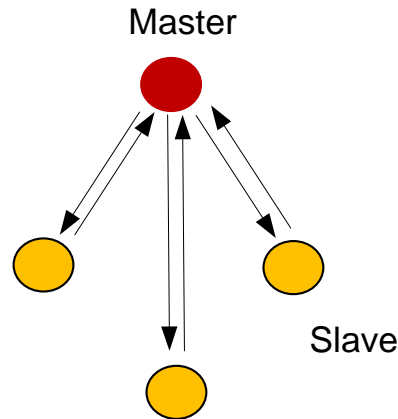
# VLC Topologies

P2P



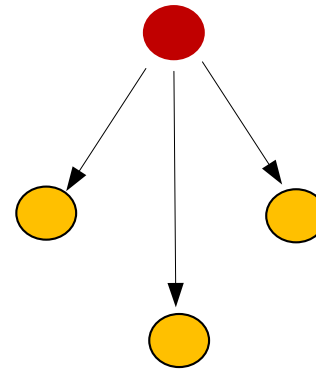
(a)

Visible LAN



(b)

Information and  
Vehicular  
Broadcasting



(c)

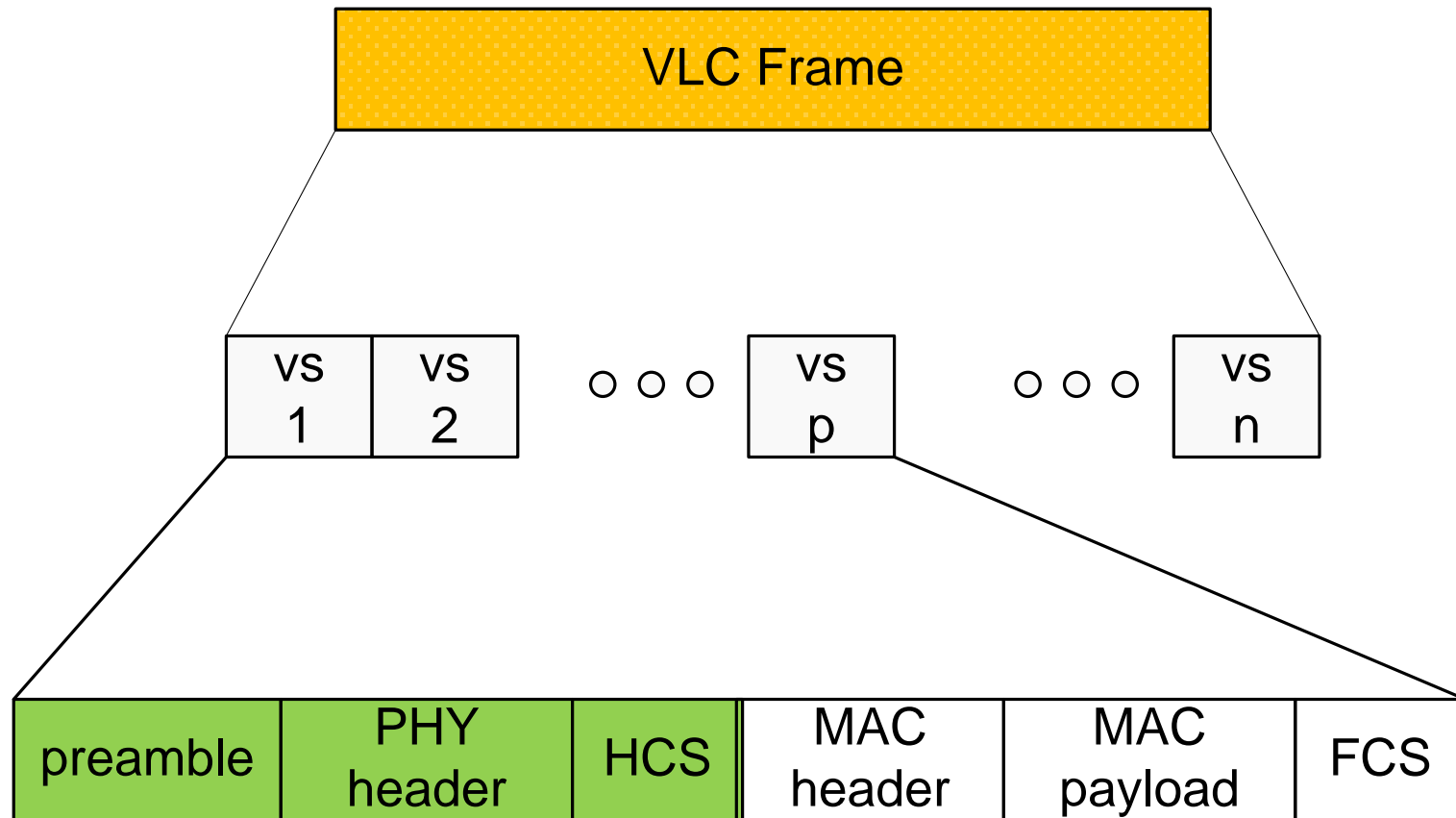
Visibility  
support



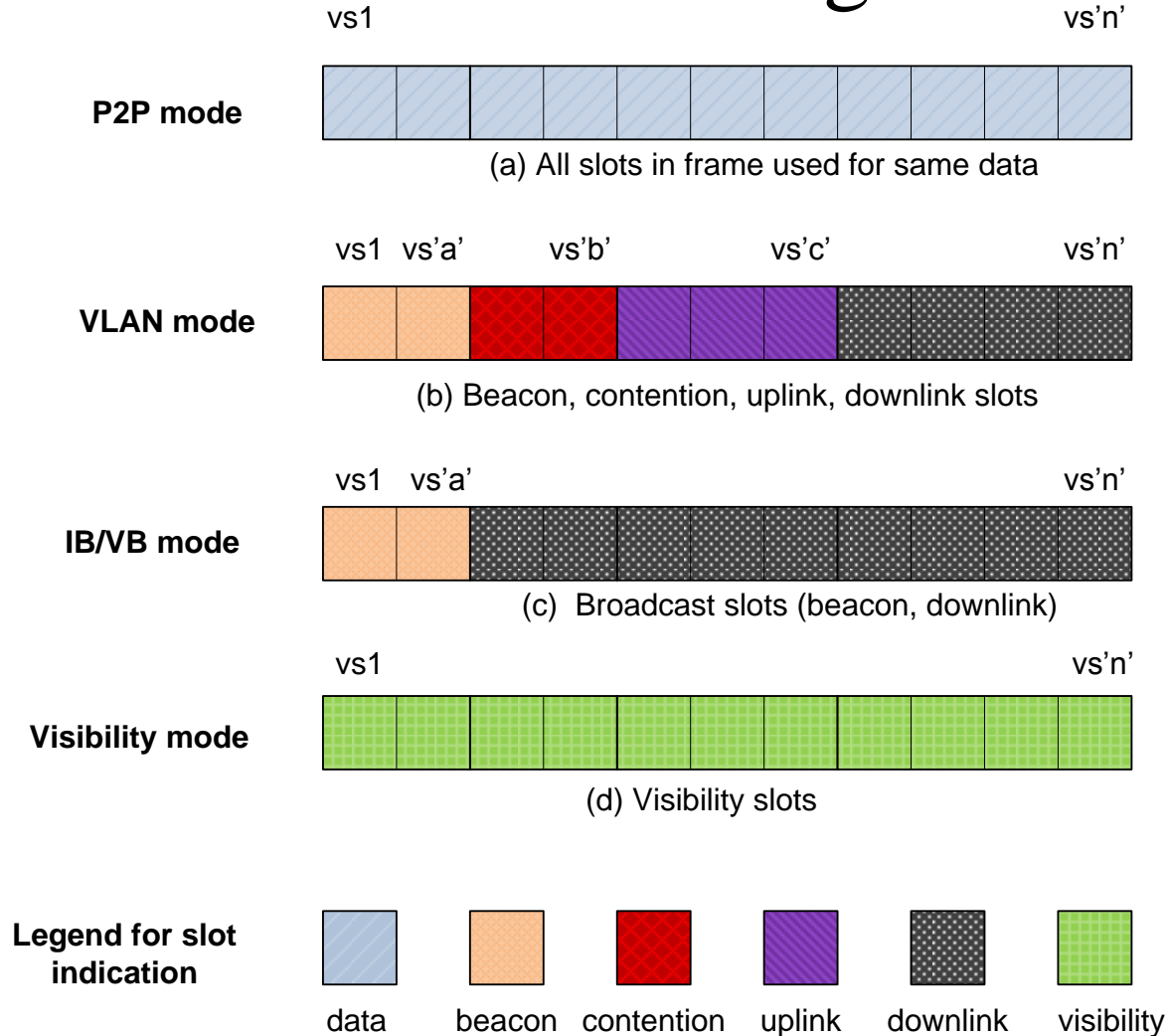
(d)



# Common VLC frame structure (Virtual slots)

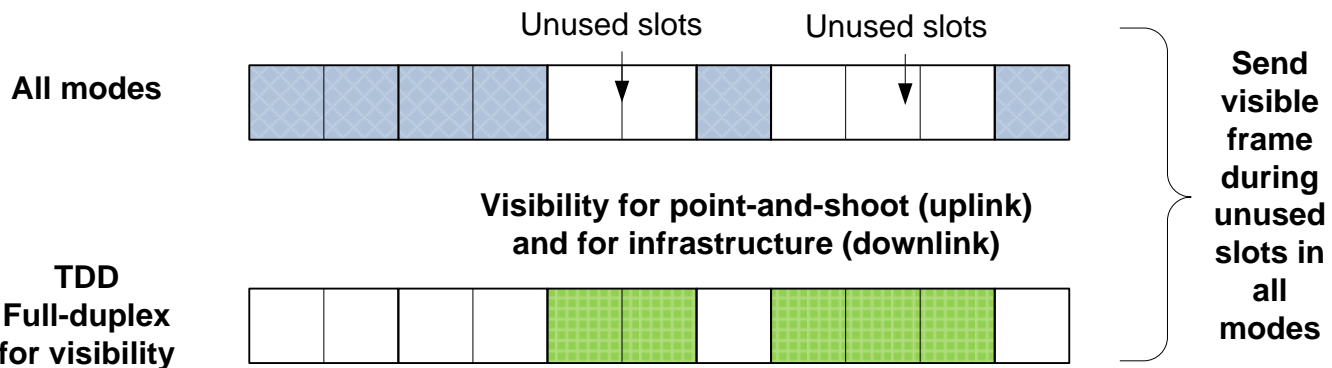
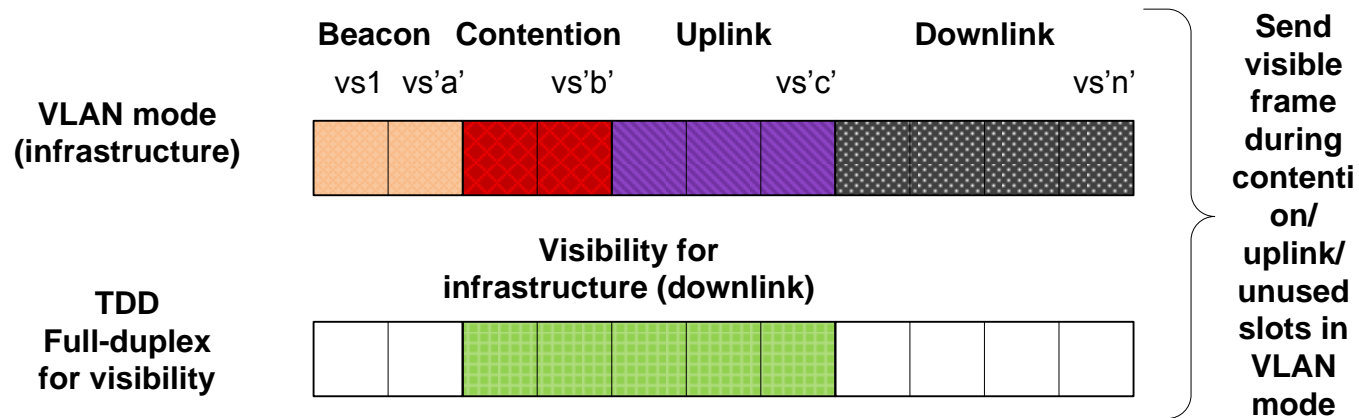


# VLC frame slot configuration



# Access mechanism

(TDD - full duplex for visibility with spatial separation)

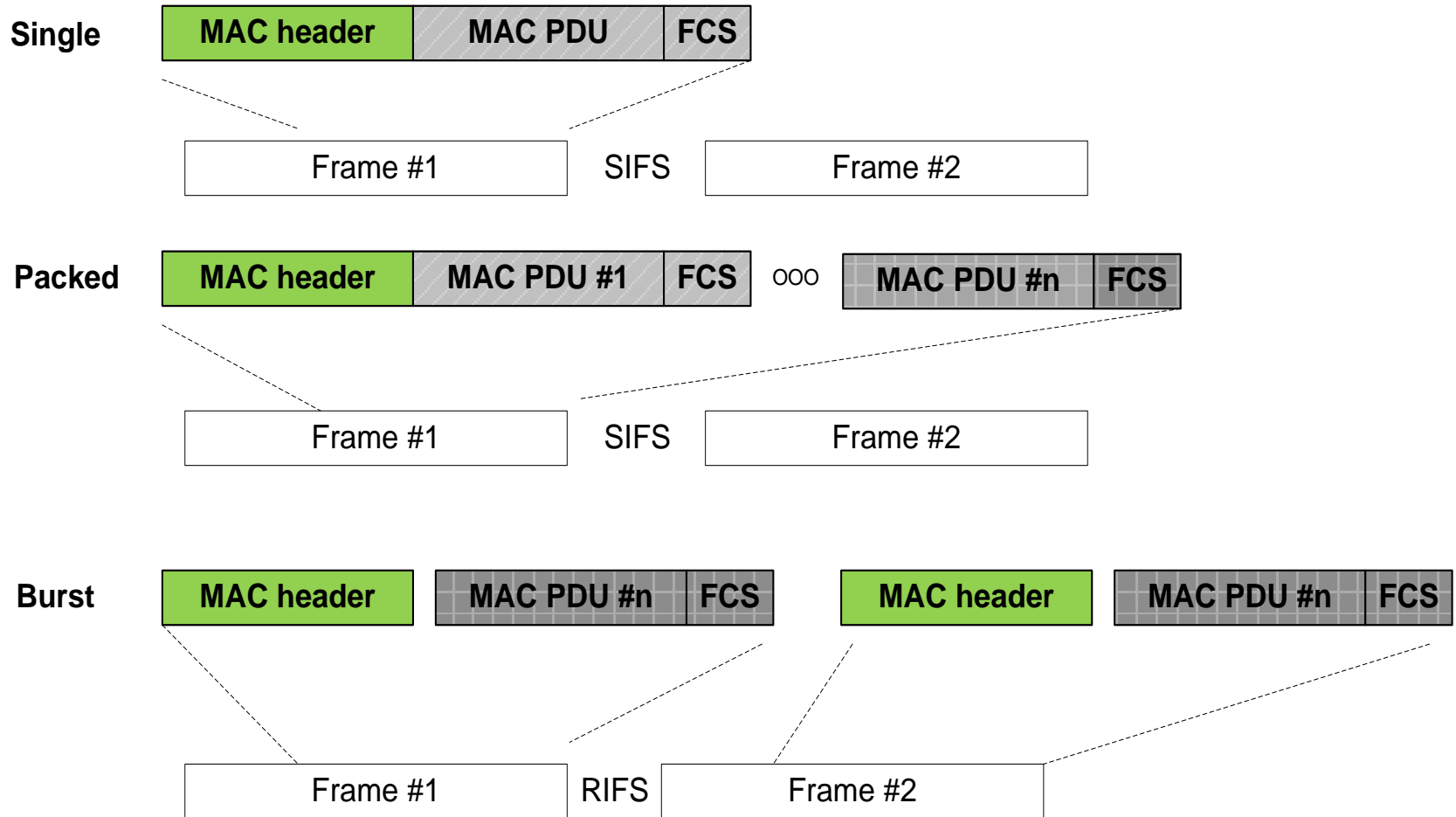


# Frame format types

Frame format type	Application	Slots used	Use
Beacon frame	VLAN, IB, VB	Beacon slots	Used by infrastructure to indicate start of frame and define number of slots to be allocated for contention, uplink and downlink. It also can tell location of active and/or in-use slots and which slots are free. Beacon frames are broadcast, have no security and do not require any acknowledgement.
Management frame	VLAN, P2P	Uplink, downlink, data slots	Are used to establish network. Are used for association, hibernation, channel change, identification, security, PHY/MAC capabilities, logical mobility/handoff etc.
Acknowledgement frame	VLAN, P2P	Uplink, downlink, data slots	Are used to acknowledge receipt of transmission (or lack of). Transmits the received sequence number of frames. Acknowledgements can be of multiple types such as single, packed or burst type
Data frame	VLAN, P2P, VB, IB	Uplink, downlink, data slots	Used for transmitting data in all modes. Can be of different types such as single, packed or burst type
Visibility frame	VLAN, P2P, VB, IB	<b>Infrastructure:</b> Contention, uplink slots, unused downlink slots for continuous visibility <b>Mobile device:</b> unused slots for point-and – shoot	Used by infrastructure to maintain visibility at ALL times in between frames and during RX and idle modes. Can be used by mobile nodes for point-and-shoot. Sends a known visibility pattern of a certain visibility percentage. Can also be used for dimming support with visibility pattern adapted to the dimming requirements (with the data being adapted to dimming pattern as well)

MAC header fields	Explanation on use	Beacon	Management	Acknowledgement	Data	Visibility
<b>Version number</b>	Allows to distinguish future versions of the standard	Set to default for current standard version				
<b>Secure</b>	Mentions whether frame is secure	No security	Frame dependent			No security
<b>ACK policy</b>	Mentions the acknowledgement policy used	No ack	Frame dependent			No ack
<b>Frame type</b>	Mentions the type of frame such as beacon, management, data	Beacon	Management	Acknowledgement	Data	Visibility
<b>Frame sub-type (dependant on Frame type)</b>	These fields are set to be dependent on the frame type	IB, VB, VLAN	Association, hibernation, channel change, device ID, PHY/MAC capabilities, security, mobility	ACK, No ACK, Negative ACK, Burst ACK, Burst Negative ACK	Single, packed, burst	Percentage visibility (or dimming)
<b>Retry</b>	Mentions if any retry is needed	No retry	Frame dependent			No retry
<b>Src address</b>	Source address of TX	Frame dependent				
<b>Destination address</b>	Receiver address – to identify intended recipient or recipients in case of multicast or broadcast	Broadcast	Frame dependent			
<b>Sequence number</b>	Tells sequence number of current PDU	No sequence number	Frame dependent			No sequence number
<b>Num PDUs per frame</b>	Tells how many PDUs can be expected in this frame	single			1 for single, 'n' for packed, burst	No PDUs
<b>Reserved fields</b>	Allows for future expansions of the MAC header	Not used for current standard				

# VLC MAC Data types



# Modes used by different applications

<b>Application</b>	<b>Type of communication</b>	<b>Data and control mode</b>
P2P, VLAN	Management, Acknowledgement	Single
IB, VB, VLAN	Beacon	Single
P2P	Data	Burst, Packed
VLAN	Data	Single, Packed
IB	Data	Single, Packed
VB	Data	Single

# Visibility

## Necessity

- Alignment (Device discovery, negotiation, connection)
- Visible guiding for user alignment
- Infrastructure continuous light output
- Blinking for unexpected interference, disconnection warnings

## Visibility on PAR

- Scope of proposed Standard: This standard ... . The visible light spectrum extends from 380 to 780 nm in wavelength. The standard is capable of delivering data rate sufficient to support audio and video multimedia services and also considers mobility of the visible link; ... ; and a MAC layer that accommodates visible links. ....
- Ref: 15-08-0656-01-0vlc-par-document.pdf



# Support for basic visibility patterns

## Visibility pattern (Percentage visibility)

**11111 11111 (100%)**

**11110 11111 (90%)**

**11110 11110**

**11101 11100**

**11001 11100**

**10001 11100**

**00001 11100**

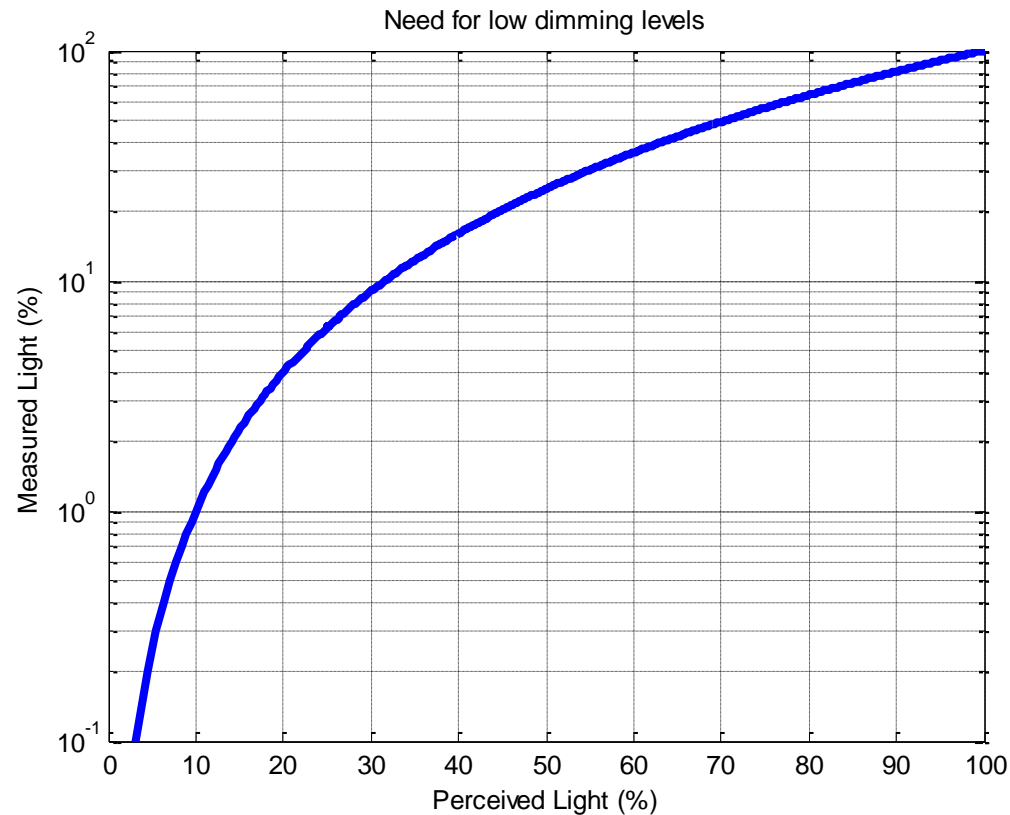
**00001 11000**

**00001 10000**

**00001 00000 (10%)**

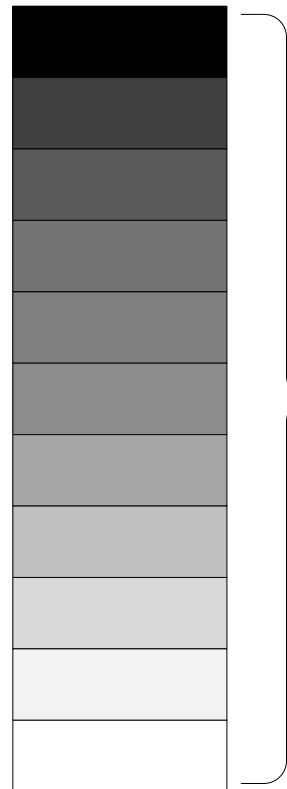
**00000 00000 (0%)**

# Support for higher resolution visibility



# Generating higher resolution visibility patterns

Fixed low resolution visibility patterns



Mix and match

New high resolution visibility patterns



# Example algorithm

It is preferable to have patterns that are chosen closer to the desired visibility to maximize transitions

For example, for attaining 25.3% visibility, we would like to maximize the use of 20% and 30% visibility patterns.

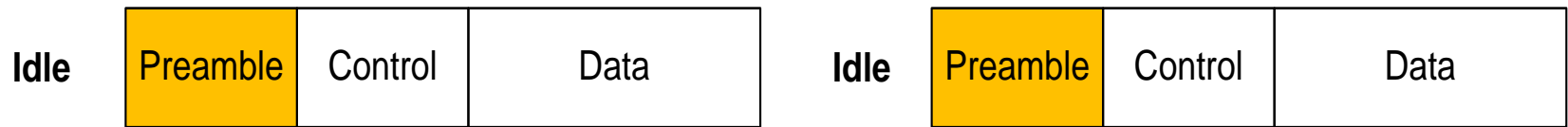
This can be done by using 20% pattern 47 times and 30% pattern 53 times

Number of ones =  $2 \cdot 47 + 3 \cdot 53 = 253$

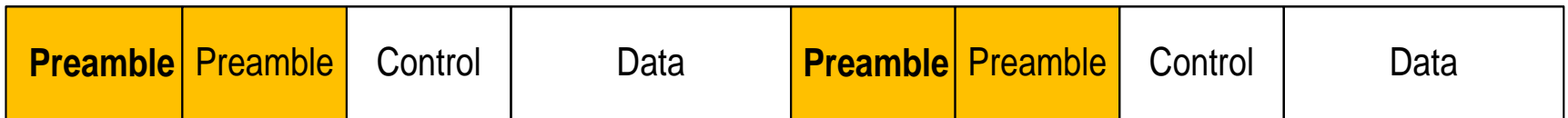
Total number =  $10 \cdot 47 + 10 \cdot 53 = 1000$

Attained visibility = 25.3%

# Extended preamble mode for visibility

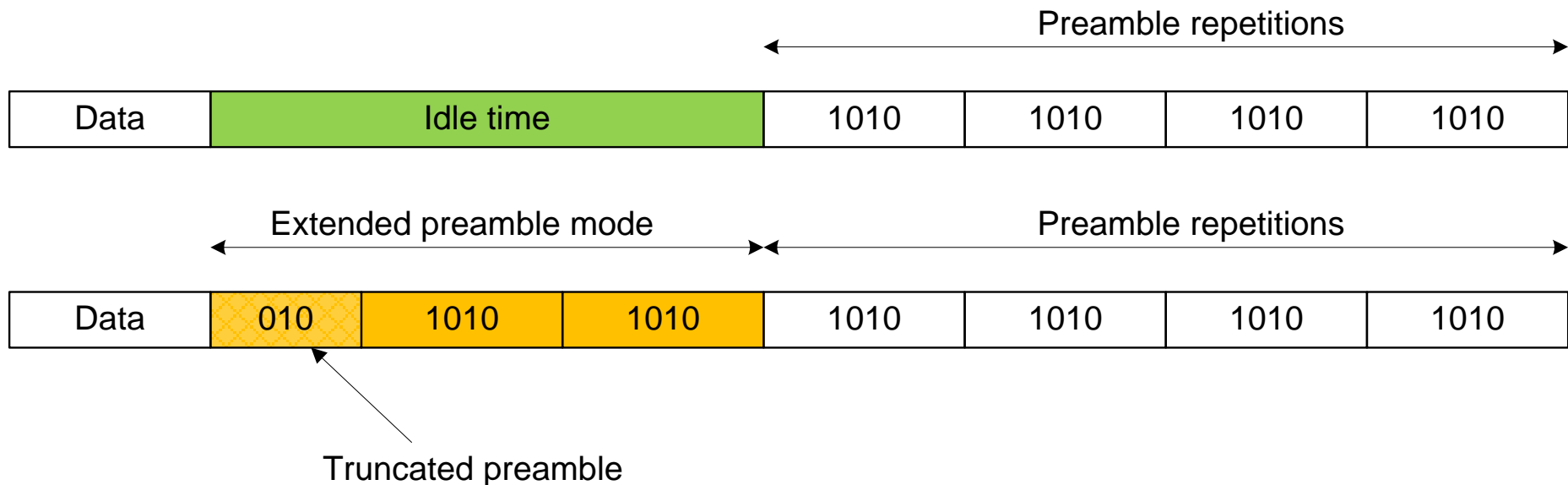


(a) Default transmission



(b) Transmit extended preamble for visibility  
and for faster and better synchronization

# Example of extended preamble mode



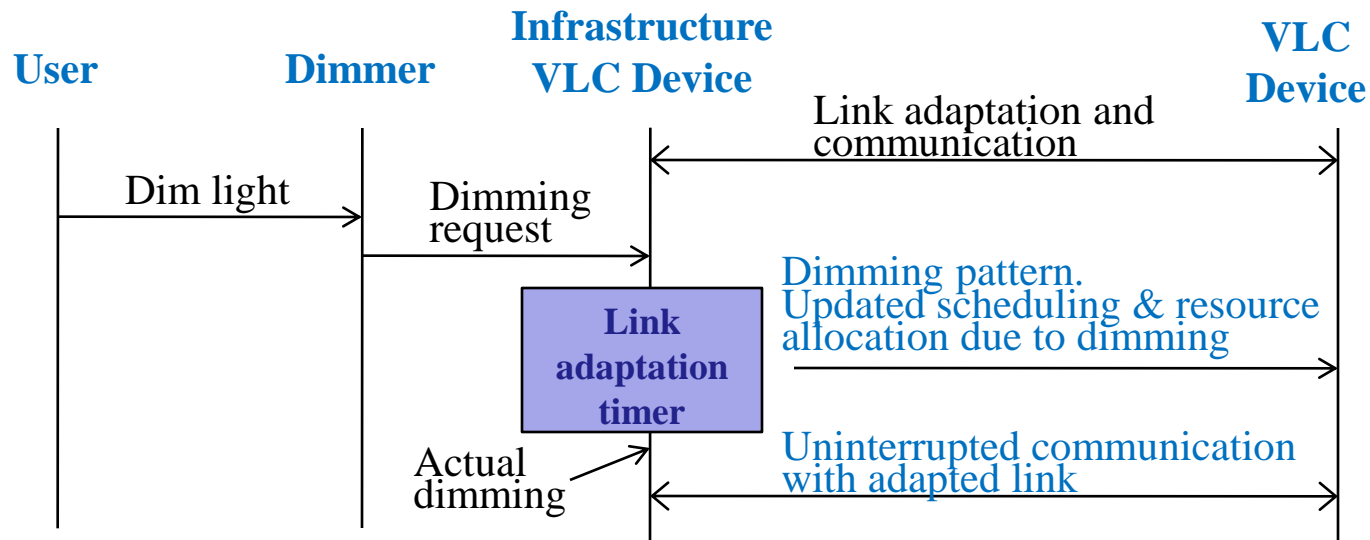
# Link adaptation for dimming support

*Dimming cycle patterns of infrastructure should be notified to VLC RX device, so that the VLC device could adapt to the dimming pattern*

Infrastructure VLC may receive a dimming request from a dimmer triggered by user

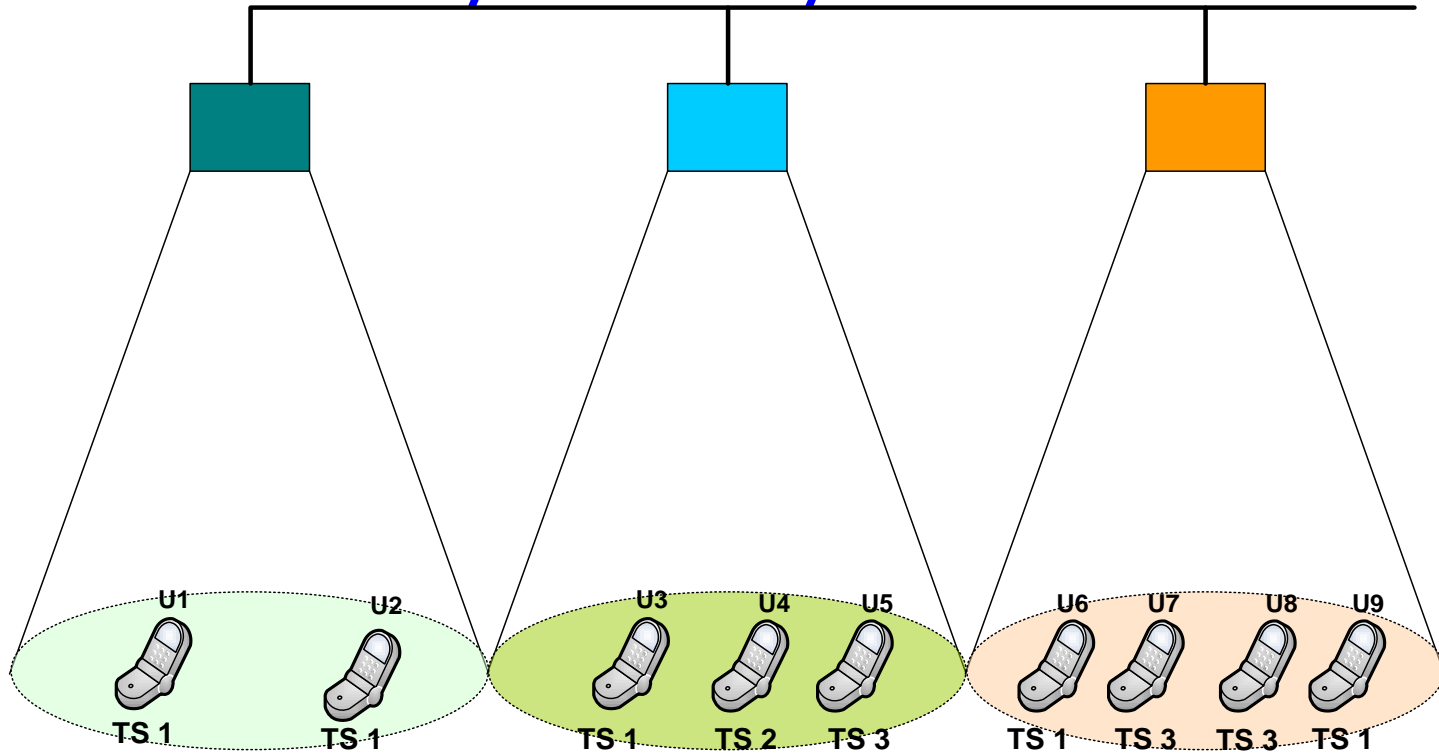
Propose to use *a link adaptation timer* that delays the time between the dimming request and the actual dimming of the light source.

With this knowledge of an incoming dimming, the link between the devices can be adapted to work at a new (lower) data rate (if dimmed) without requiring the link to be interrupted or possible link failure.

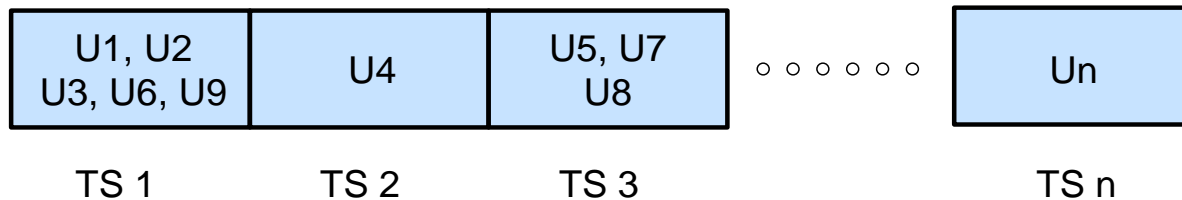


# Multiple channel support

## Unicast/Broadcast/Multicast

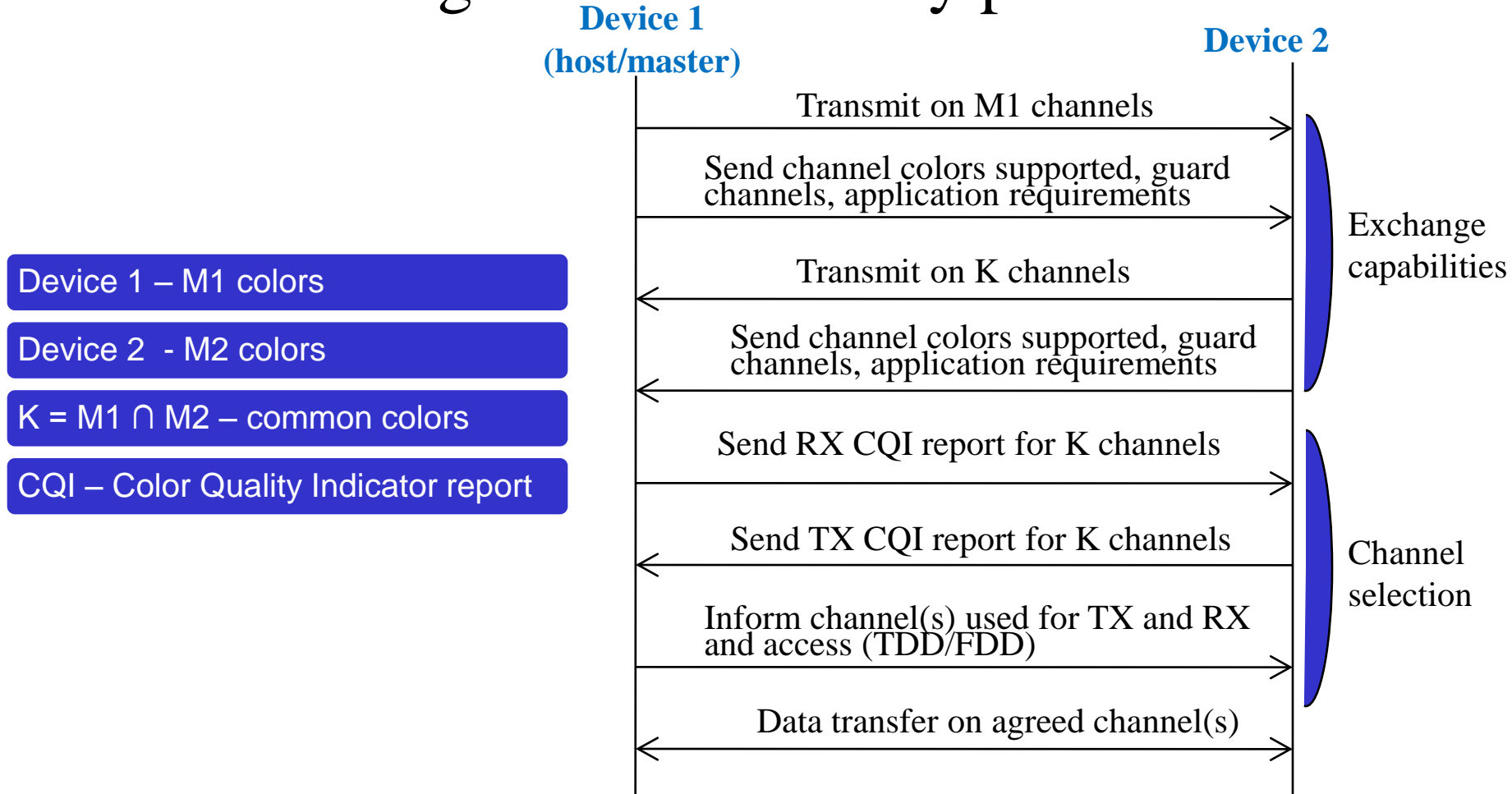


U : user  
TS : time slot





# Exchanging capabilities and channel selection during device discovery process



# Capabilities Information Element for device discovery

## PHY capabilities:

- Colors supported
- Data rates
- Guard colors for each supported color

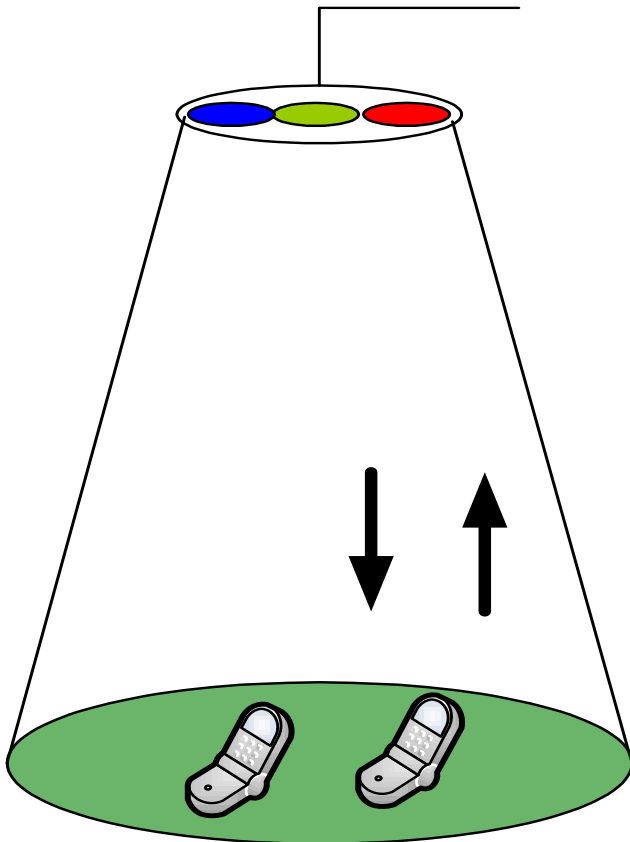
## MAC capabilities:

- Uni-directional traffic support
- Bi-directional traffic support
- P2P support
- P2MP support
- Visibility/Dimming support

# Multiple channel resource assignment

MS (Destination) reports available channel resource

Can expand to many channels

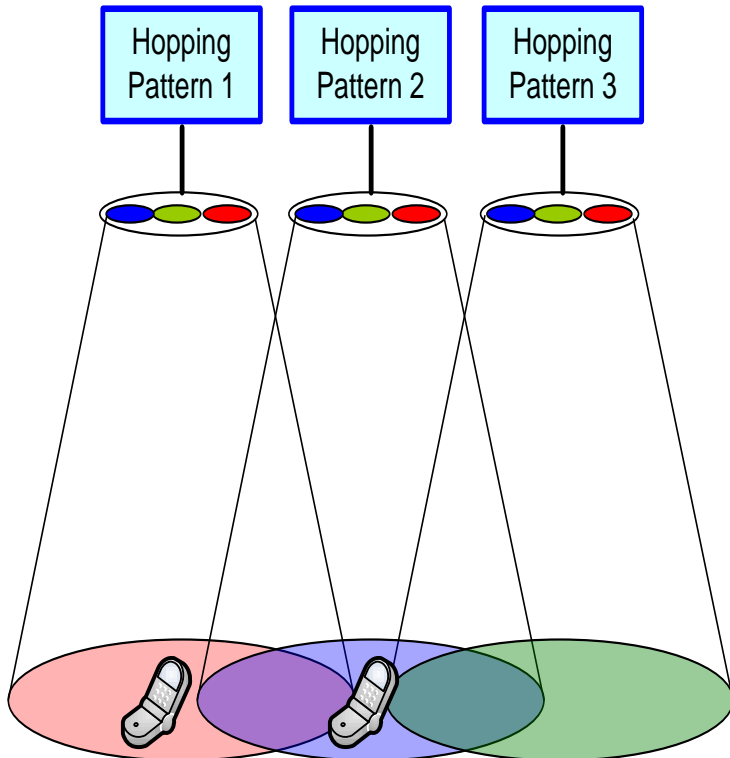


Ch	Bit	R	G	B
1	000	○	○	○
2	001	○	○	×
3	010	○	×	○
4	011	×	○	○
5	100	○	×	×
6	101	×	○	×
7	110	×	×	○
8	111	×	×	×

# Channel hopping for interference avoidance

In order to avoid interference by hopping pattern

Resource enhancement



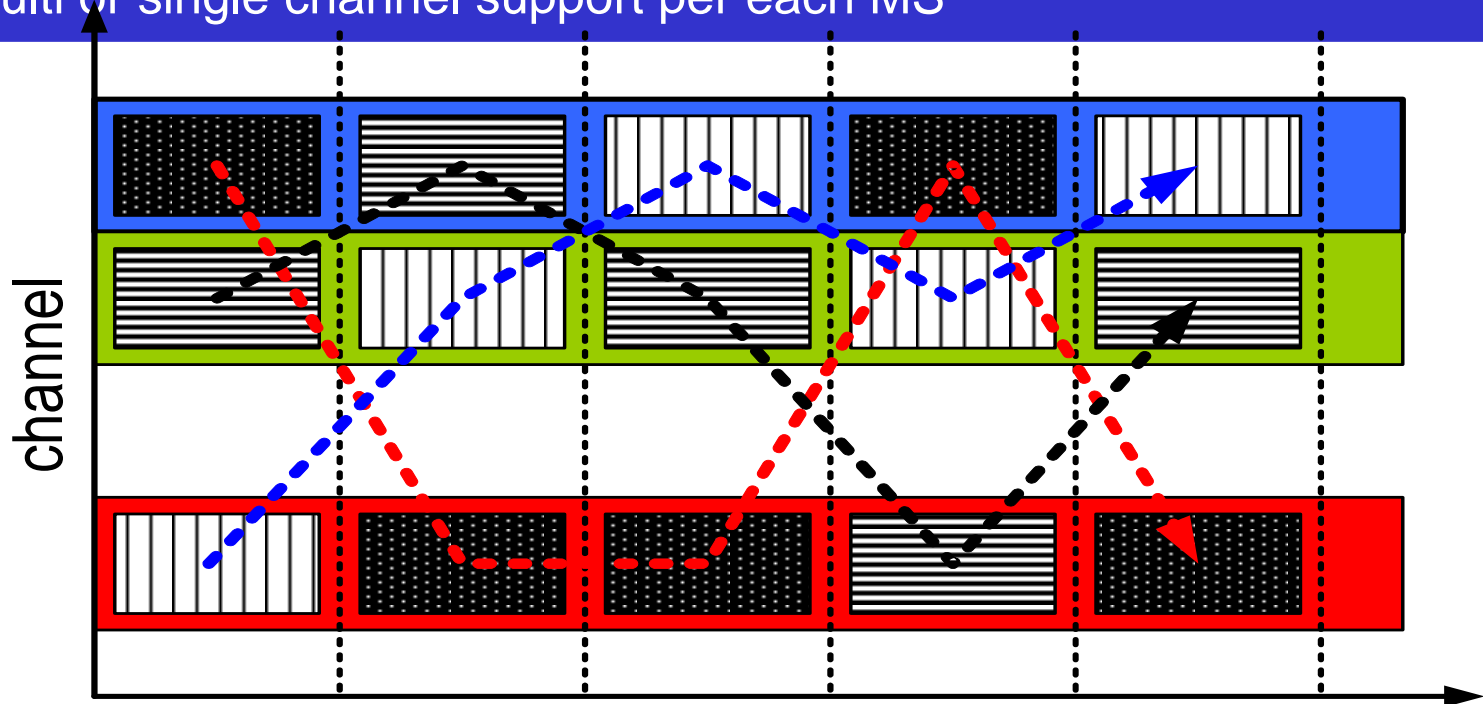
pattern set	001	011	101
Frame/time slot	HP 1	HP 2	HP 3
1	R	G	B
2	B	G/R	B
3	G	R/B	G
4	G/R	B	G/R
5	G/B	R	G/B
6	R/B	G	R/B
7	G	B	R
8	B	R	G
9	R	G/B	R

# Multiple channel hopping

Hopping based some frame/time slot

Hopping and non hopping mode support

Multi or single channel support per each MS



# Blinking notification

Depending on the FOV, TX power and the mobility of devices, it is possible that the link may occur only in 1 direction.

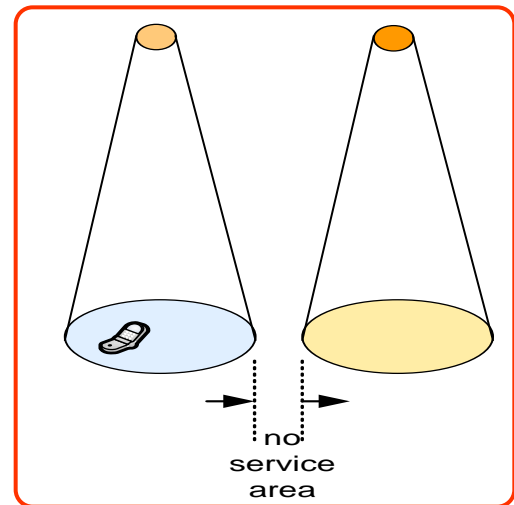
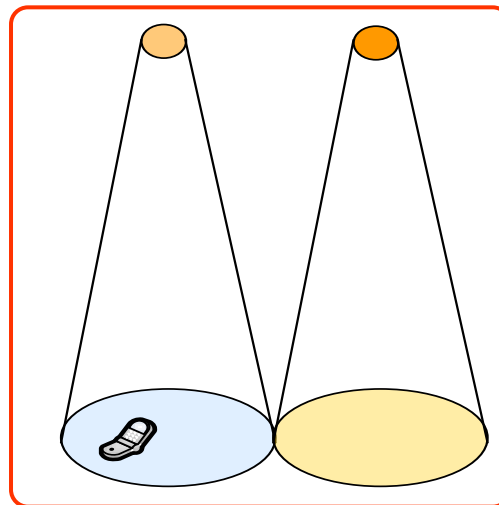
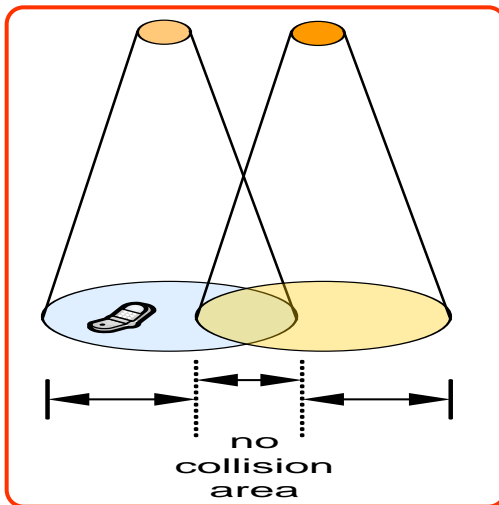
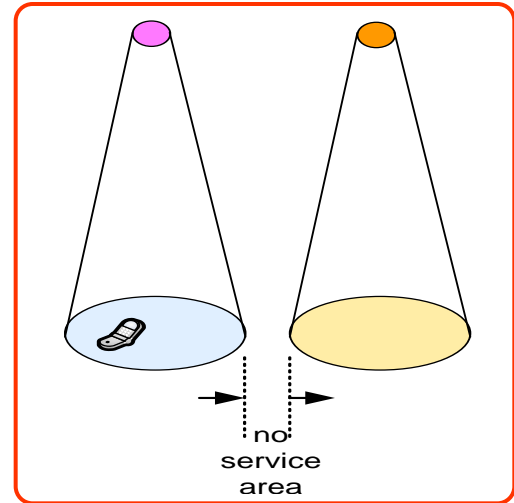
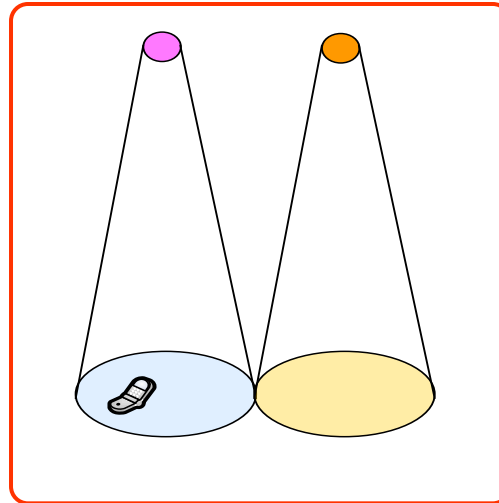
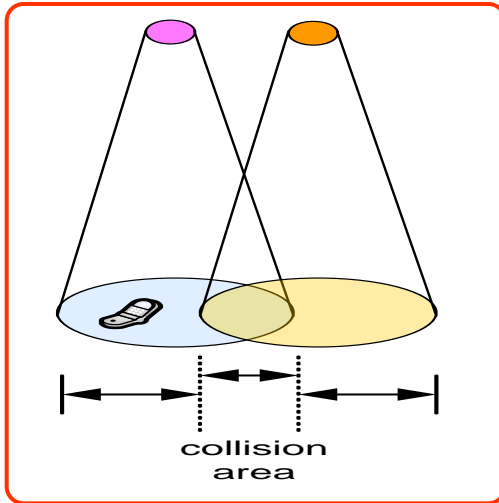
In such cases, the mobile needs to change the visibility indication from continuous visibility for point-and-shoot to blinking indication

For example, if the infrastructure cannot receive uplink but the mobile is able to receive downlink, the AP can indicate to mobile about the lack of reception and request a visibility indicator change for the user

The mobile can then change from point-and-shoot mode to blinking mode to indicate the user that the connection may be getting disconnected.

This indication can be applied to both P2MP and P2P modes of operation

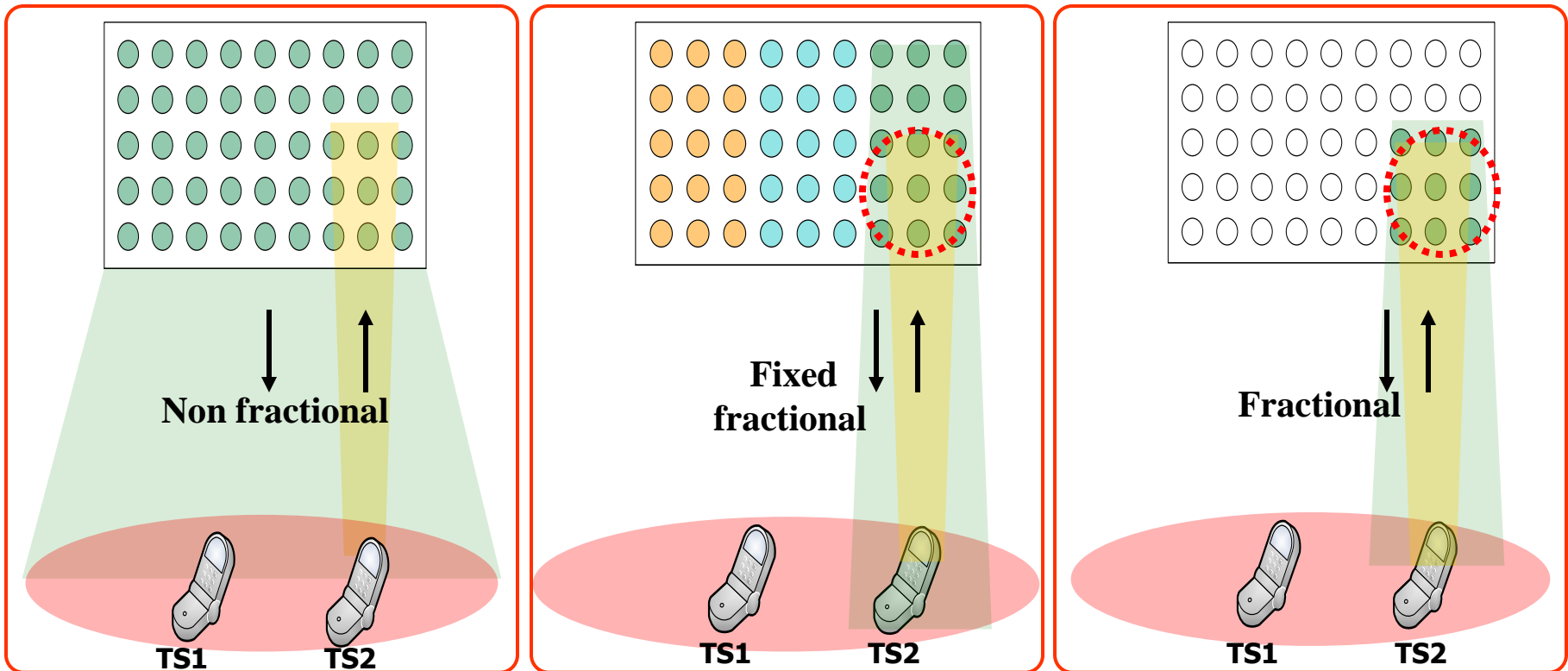
# Supporting mobility across piconets



# Mobility support within a piconet

## Fractional cell assignment based on signal detection

- enhancement capacity and avoiding interference
- low power consumption





<b>Additional fields in management payload</b>	<b>Explanation on use</b>
<b>Src_multi_info</b>	Source multiple channel resource assignment
<b>Des_multi_info</b>	Destination multiple channel resource assignment
<b>S_info</b>	Time slot information for multiple channel
<b>H_pattern</b>	Multiple channel hopping
<b>VF_info</b>	Visibility frame notification for source and destination
<b>Src_mode</b>	Granular and single source notification
<b>G_cell_ID</b>	Granular cell assignment
<b>Fractional_Src</b>	Fractional source notification
<b>Mode_type</b>	Multicast/broadcast/unicast announcement
<b>S_Release_slot</b>	Start and release slot for broadcasting
<b>Spatial mobility</b>	Request spatial mobility to AP

# Other MAC features under development that is required for IEEE 802.15.7

Security

Power saving schemes

Others

# Conclusion

	<b>IEEE 802.15.7 VLC</b>		
<b>Application</b>	<b>VLAN/IB/VB</b>	<b>VLAN</b>	<b>P2P</b>
<b>Link</b>	<b>Downlink</b>	<b>Uplink</b>	<b>Downlink/Uplink</b>
<b>wavelength</b>	<b>380nm~780nm</b>		
<b>Optical channel</b>	<b>Multiple</b>	<b>Multiple (possible) Single (preferred)</b>	
<b>Line coding</b>	<b>8B10B</b>		
<b>Duplexing</b>	<b>TDD Half (except for visibility)</b>		
<b>Frame slot</b>	<b>Slot</b>		<b>Non slot</b>
<b>Data rate</b>	<b>6.4 Mbps (Min) / 96 Mbps (Max)</b>		
<b>Mobility</b>	<b>Support</b>		<b>None</b>
<b>Frame type</b>	<b>Data/Visibility/Management/Beacon/Ack</b>		<b>Data/Visibility/Management/Ack</b>

# Summary

An initial proposal for VLC MAC is presented for TG7 consideration

Supports P2P, IB, VB, VLAN applications

Single MAC design with single MAC header to support multiple applications

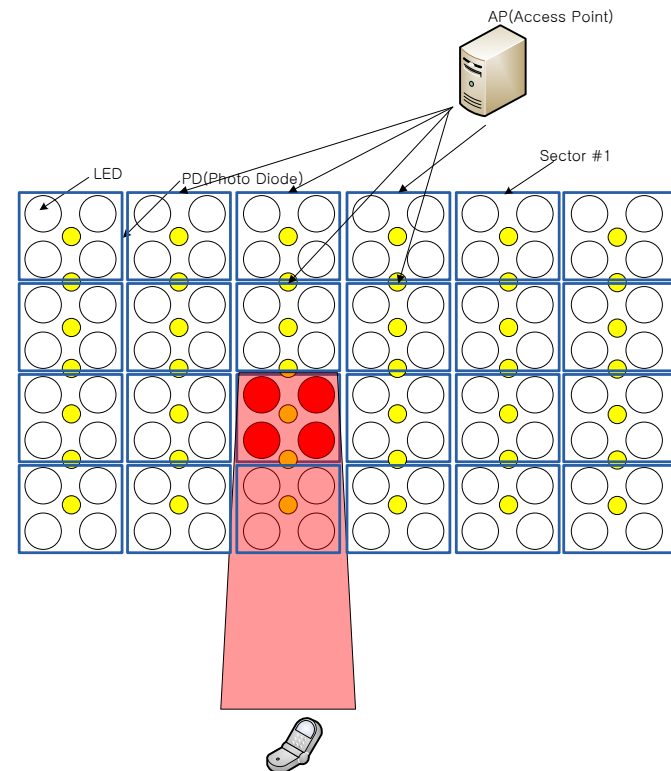
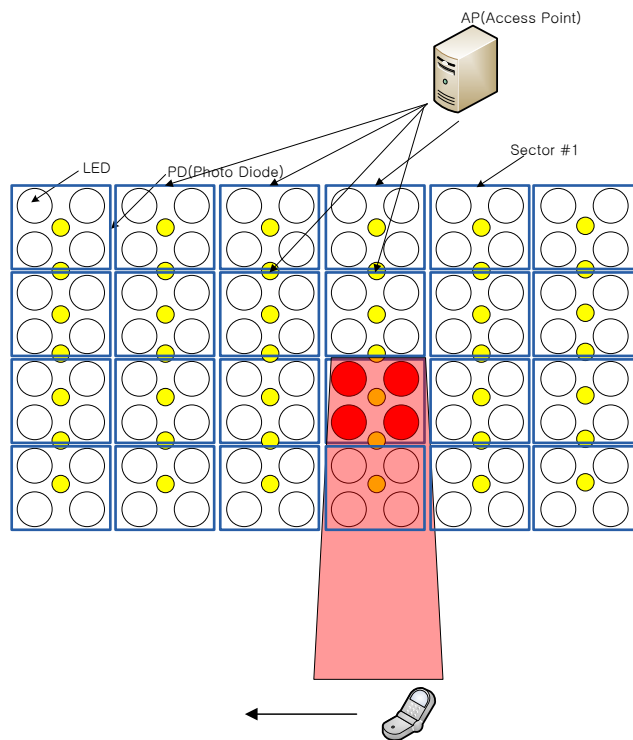
Provides support for visibility/dimming and mobility features

# Appendix

# Spatial Mobility

MS (Destination) request spatial mobility to APs

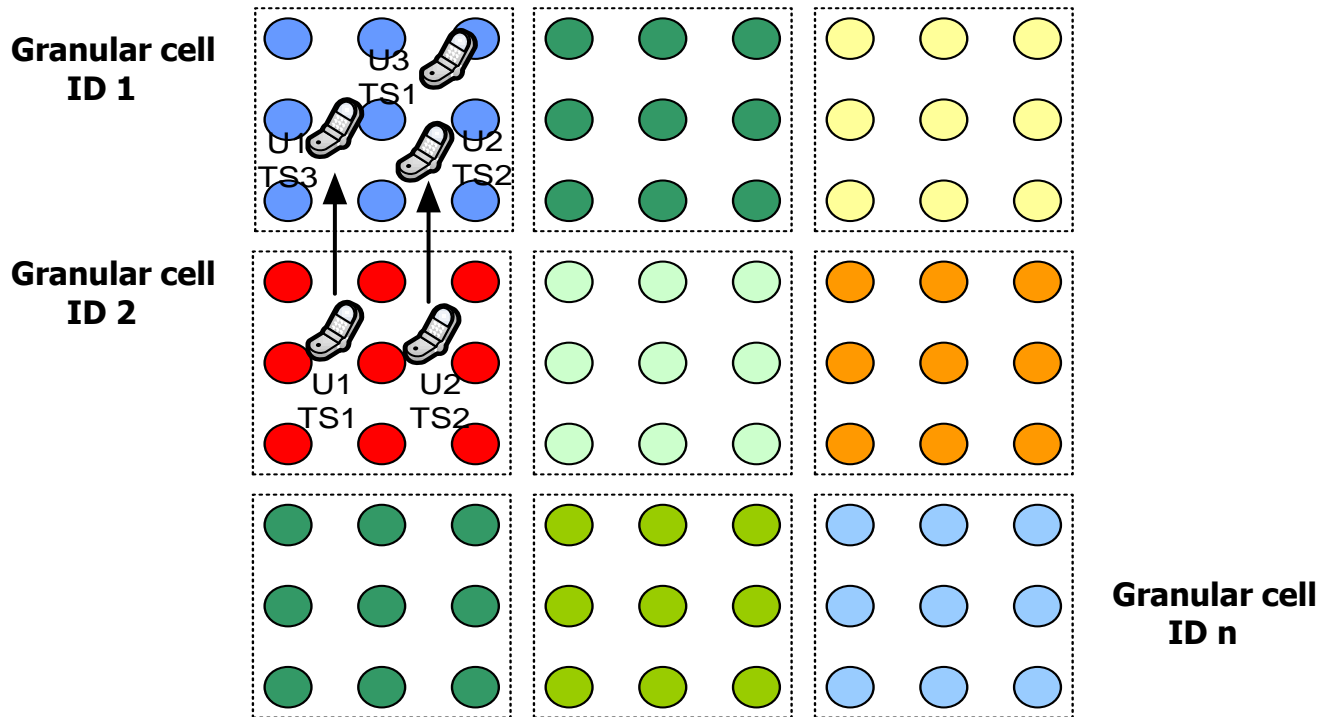
- Support VLC device mobility
- Low power consumption



# Slots assigned by mobile movement

## Granular cell assignment

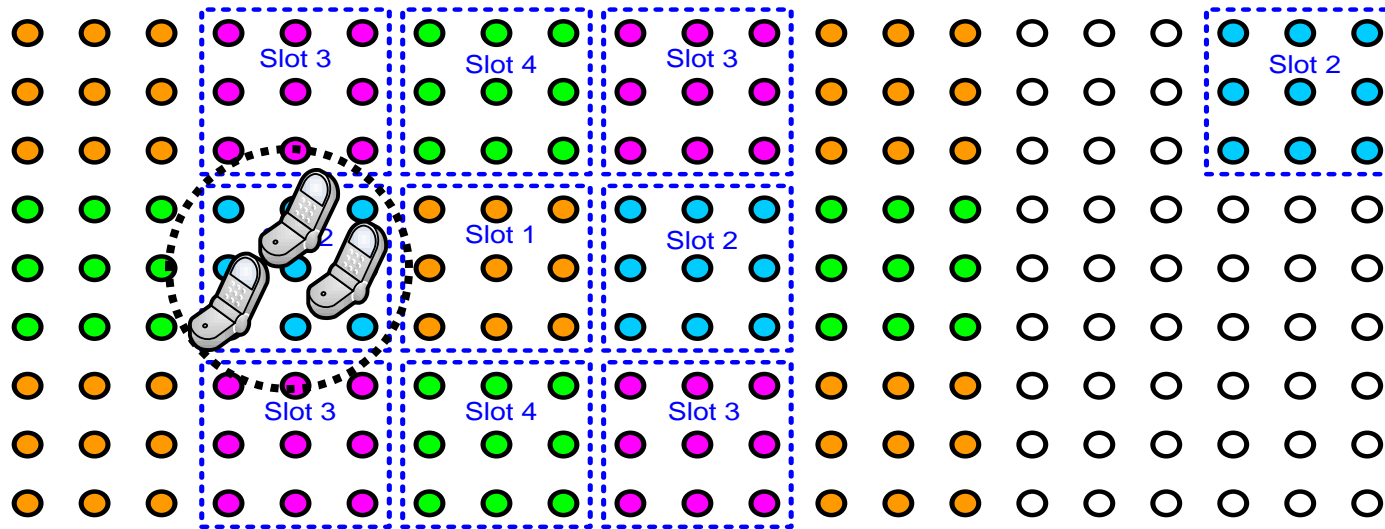
- support VLC device mobility
- optical source grouping



# Fixed slots assignment with re-use

## Granular cell assignment

- support VLC device of IB service mobility
- optical source grouping



Time slot reuse for interference avoidance