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Radio Network Overview and Network Design Principles

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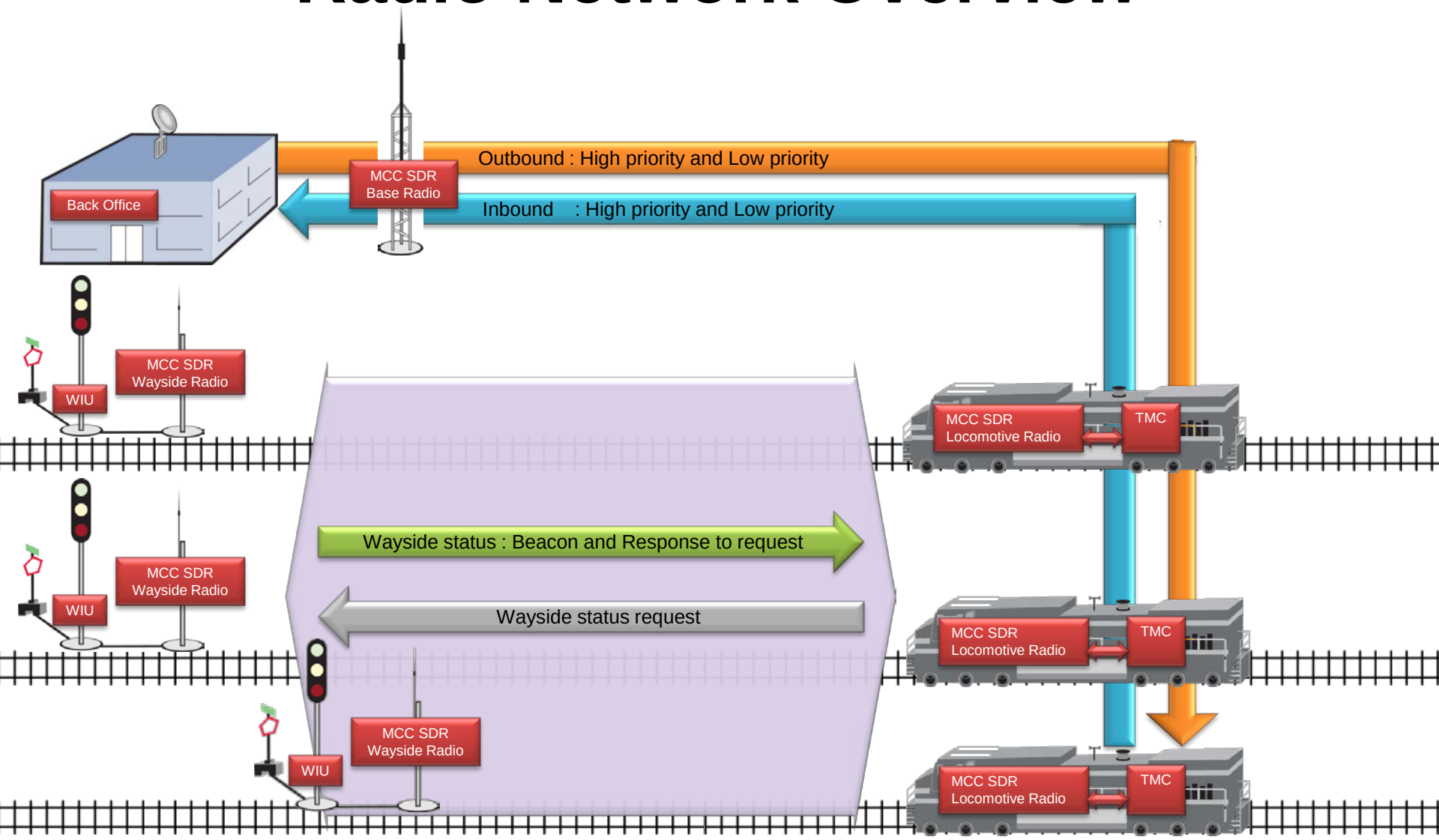
Document Number: 00002152-A

Outline

- Radio network overview
  - Basic components of PTC radio network
  - Radio characteristics
  - ITCnet® protocol
- Network design principles
  - Network design overview
  - Base and wayside coverage planning
  - Base frequency planning
  - Wayside slot planning

Radio Network Overview

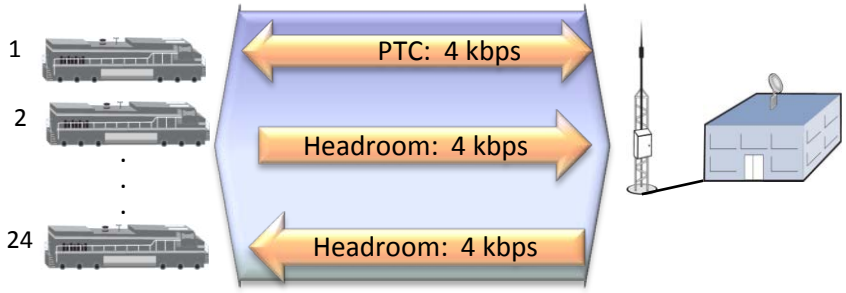


ITC Requirements

- Throughput

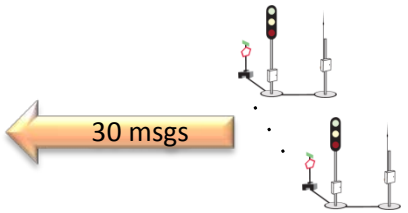
Office-Loco Traffic Load

- 4 kbps PTC (inbound or outbound)
- 8 kbps Headroom (4 kbps inbound and 4 kbps outbound)



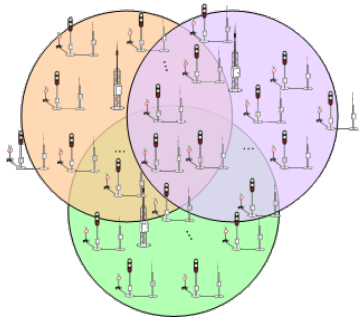
Wayside Traffic Load

- 30 WIU status messages every 3 seconds



High Density Waysides

- Maximum density of 2.55 messages per square mile



High Density Non-PTC Locomotives

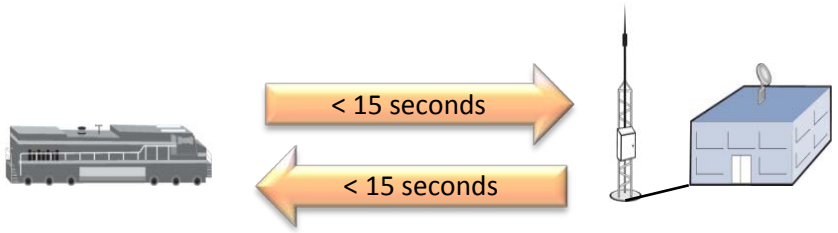
- Support 450 non-PTC locomotives with radios on under a base

ITC Requirements (Cont.)

- Latency and Reliability

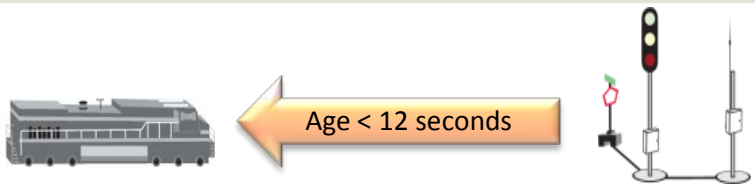
Office-Loco Traffic: PTC messages

- Latency of high priority outbound/inbound messages: < 15 seconds for 99.9% of messages

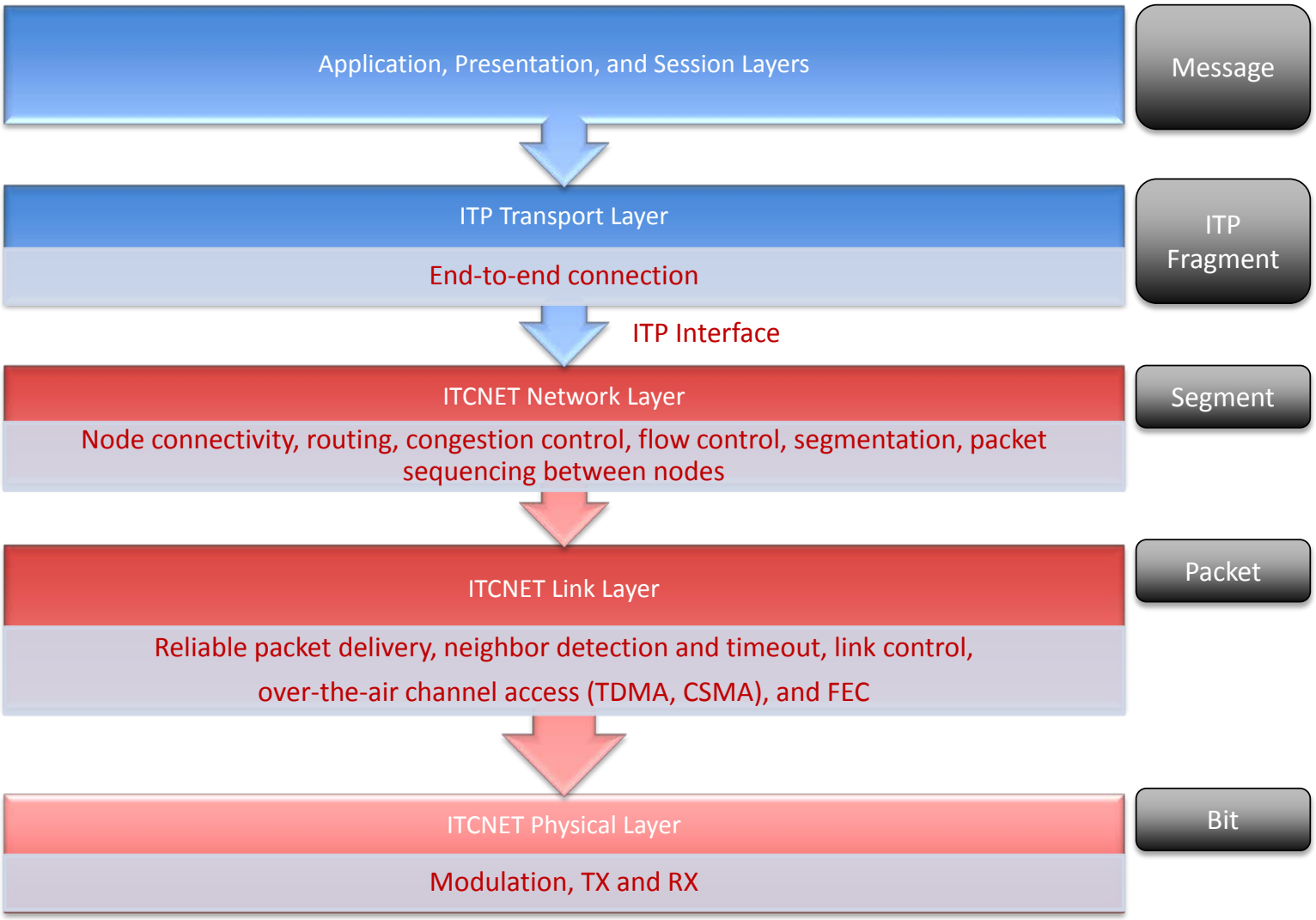


Wayside Traffic: WIU status messages

- Age of WIU status message at TMC: < 12 seconds for 99.9999% of messages



Overview of ITCnet Protocol



ITCnet Physical Layer

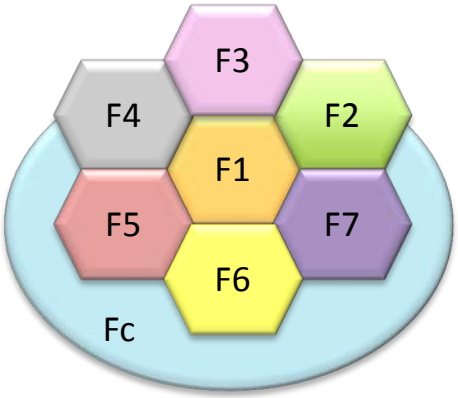
- **Characteristics of ITC Radios**

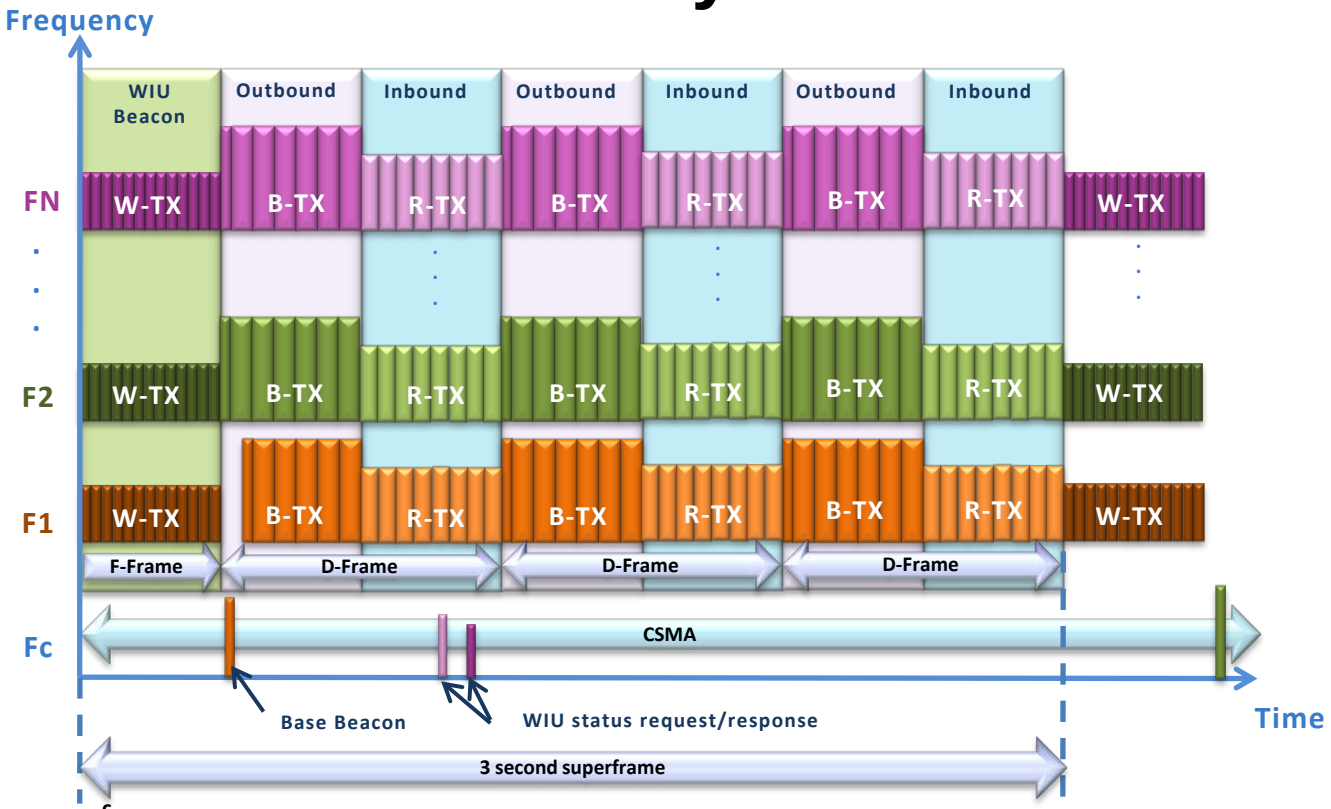
	Wayside Radio	Locomotive Radio	Base Radio
Application	Fixed remote installations	Mobile remote installations	Base station installations
Frequency Band	217.6 - 222.0 MHz	217.6 - 222.0 MHz	217.6 - 222.0 MHz
TX Modulation	$\pi/4$ DQPSK	$\pi/4$ DQPSK	$\pi/4$ DQPSK
TX Bit Rate	16 kbps	16,32 kbps	16,32 kbps
Peak TX Power	25 Watt	50 Watt	75 Watt
Average TX Power	12.5 Watt	25 Watt	37.5 Watt
Channel Spacing	25 kHz	25 kHz	25 kHz

- Number of physical receive channels

Radio Type	Primary Receive Channels	Diversity Receive Channels
Wayside	2	0
Locomotive	8	8
Base	8	8

ITCnet Link Layer

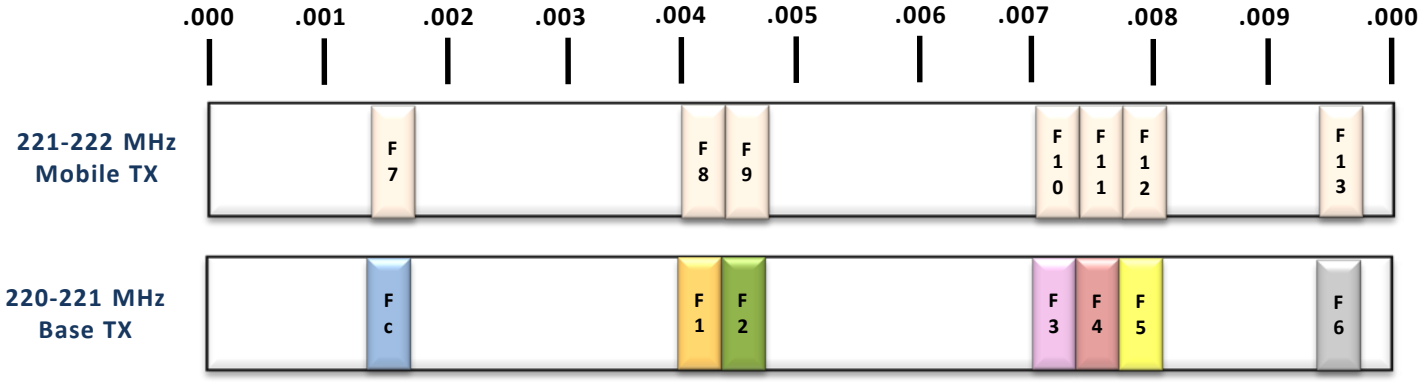




- 1 Common channel + N Local channels

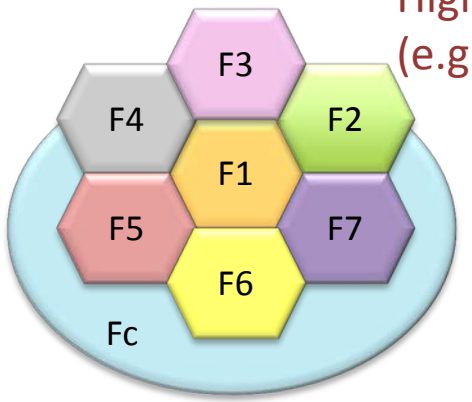
- Local channel: 3-seconds superframe
  - F-Frame: WIU status beacons
  - D-Frame: outbound and inbound traffic from remotes under a base
- Common channel is accessed by CSMA. The common channel supports
  - Base beacon – for remote to select a base
  - WIU status request and response in 'panic' mode; WIU beacon on
- Tx in F-Frame slots rely on GPS timing; Tx in D-Frame slots rely on base polling
- Base beacon is transmitted in both local and common channels

ITCnet Channelization

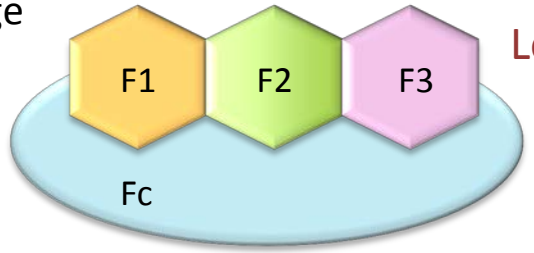


- 14 Nation 25kHz channels available
- One 25kHz channel is set as common channel;
  the rest are set as local channels
- Common channel is shared by all bases and remotes
- Local channel is used to support
  - WIU status messages
  - Traffic between base and remotes under base coverage
- Frequency reuse is applied to local channels to increase spectral efficiency and mitigate co-channel interference

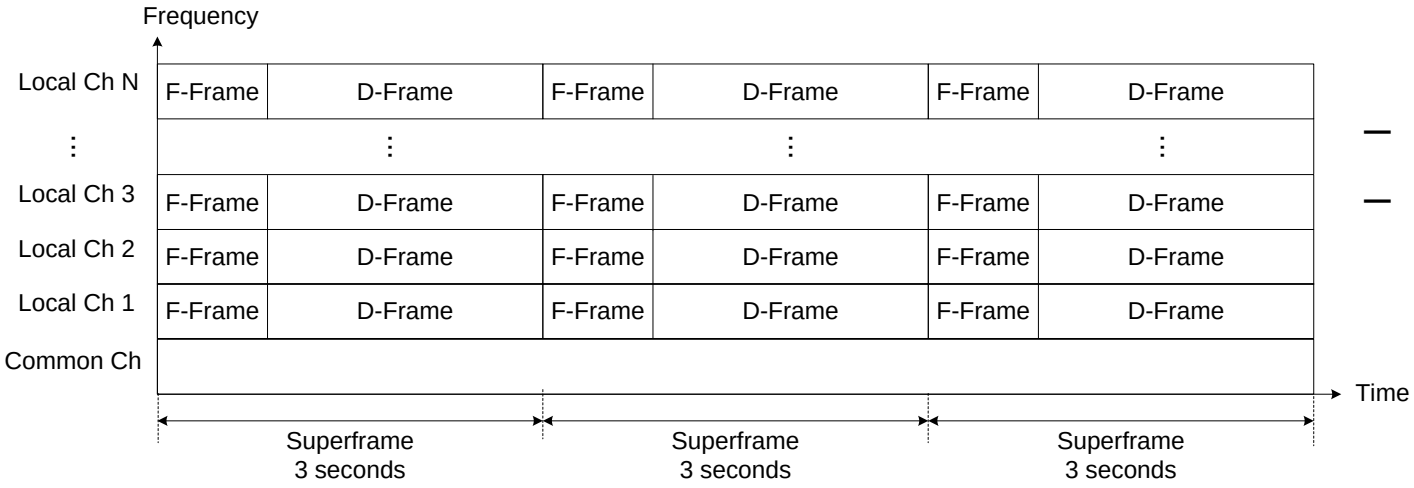
High density
(e.g. 7, 13 reuse)



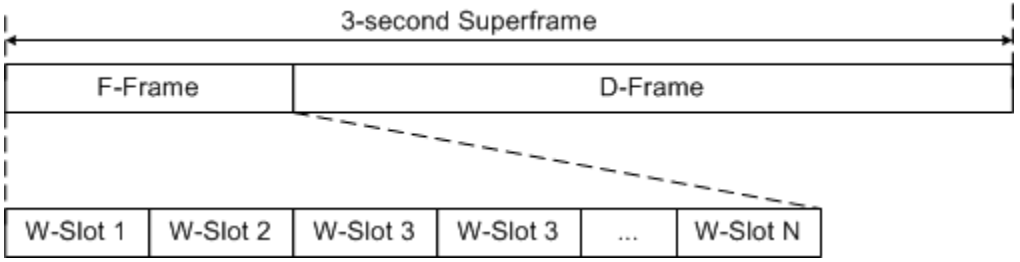
Low density



ITCnet Channel Structure



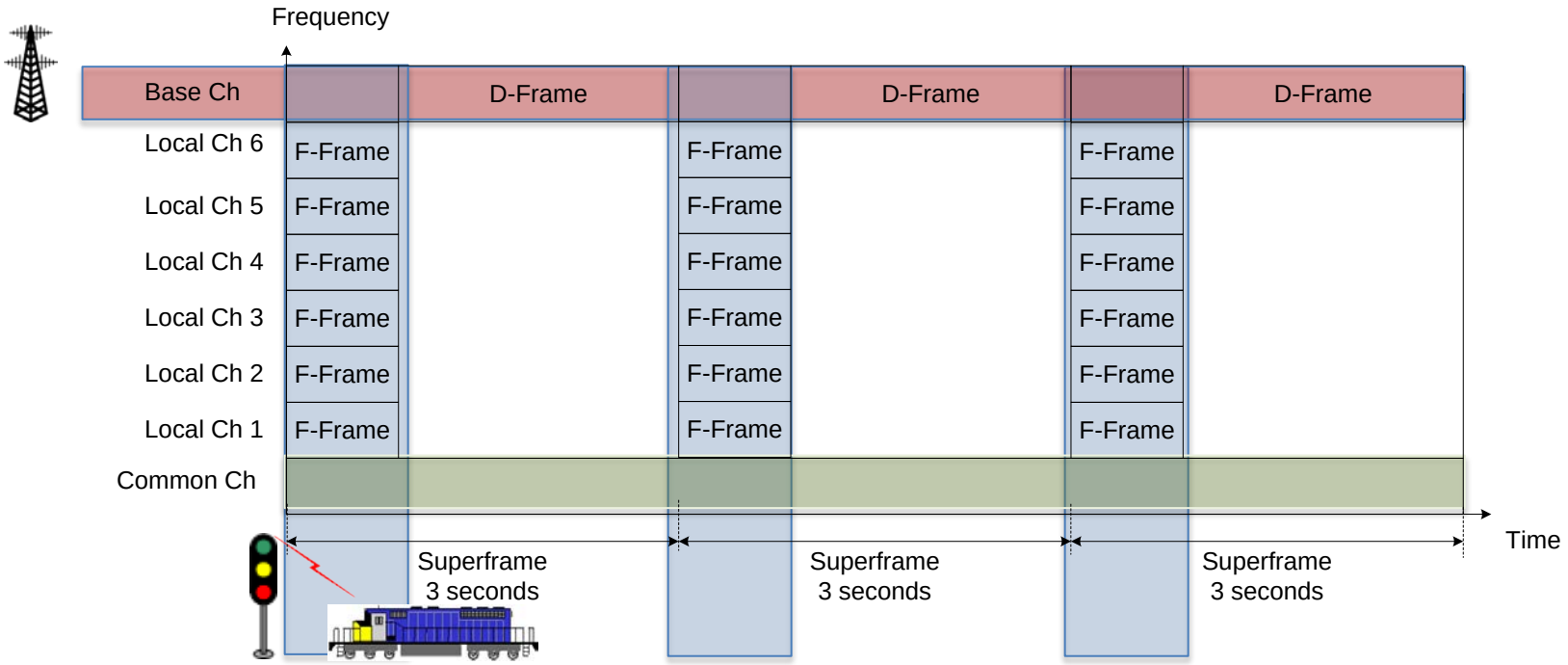
- 1 Common channel
- N Local channels
  - N is number of available local channels
  - N can be more than 7 channels



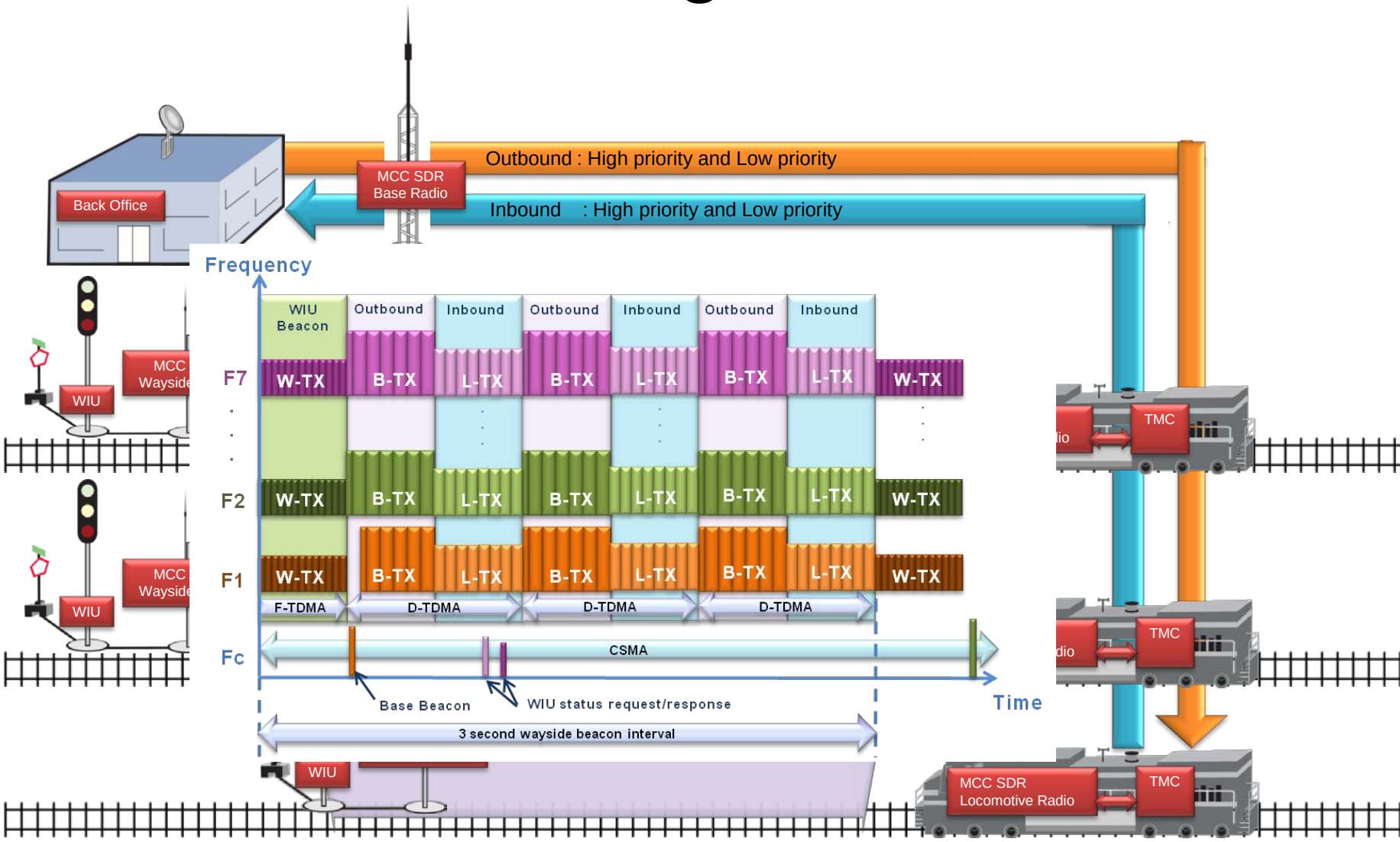
- WIU status tx in W-Slot in F-Frame
  - 1 WIU message per slot
- The rest tx in D-Frame

ITCnet (Cont.)

- Base/Locomotive radios
  - 8 Receive channels
    - 1 Common channel
    - 7 Local channels
      - 1 to connected base for base-locomotive communication during D-Frame
      - 6 to receive WIU status during F-Frame



Network Design Overview



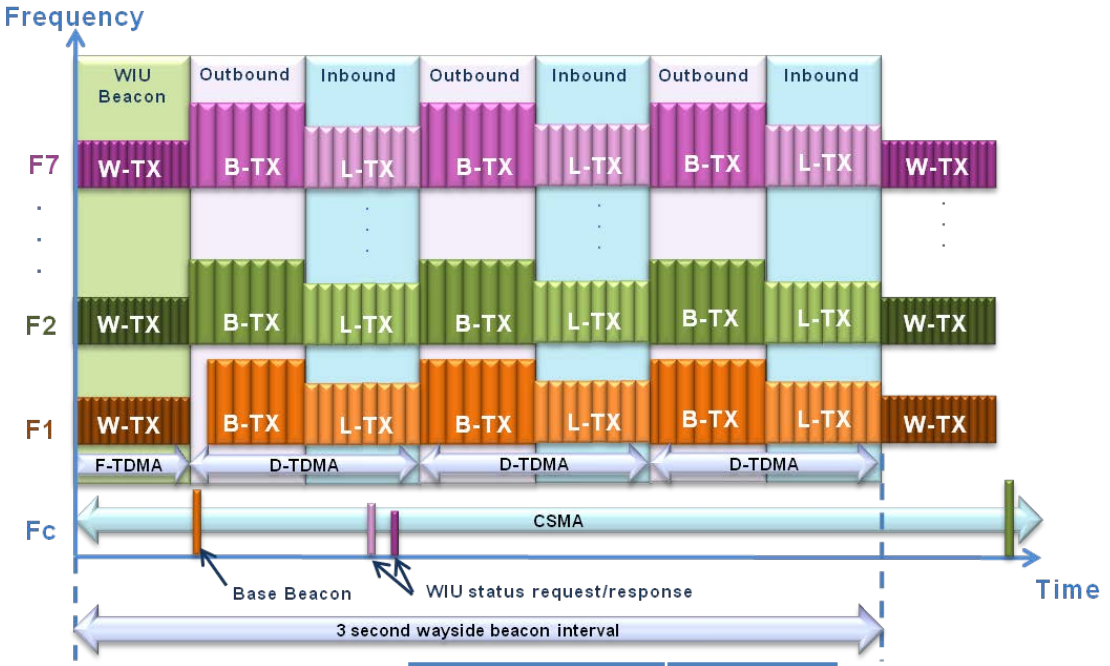
Network Design Principles

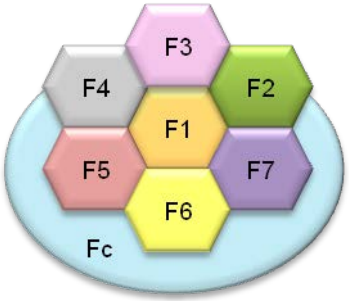
Common Channel Selection

Coverage Planning

Base Frequency Planning

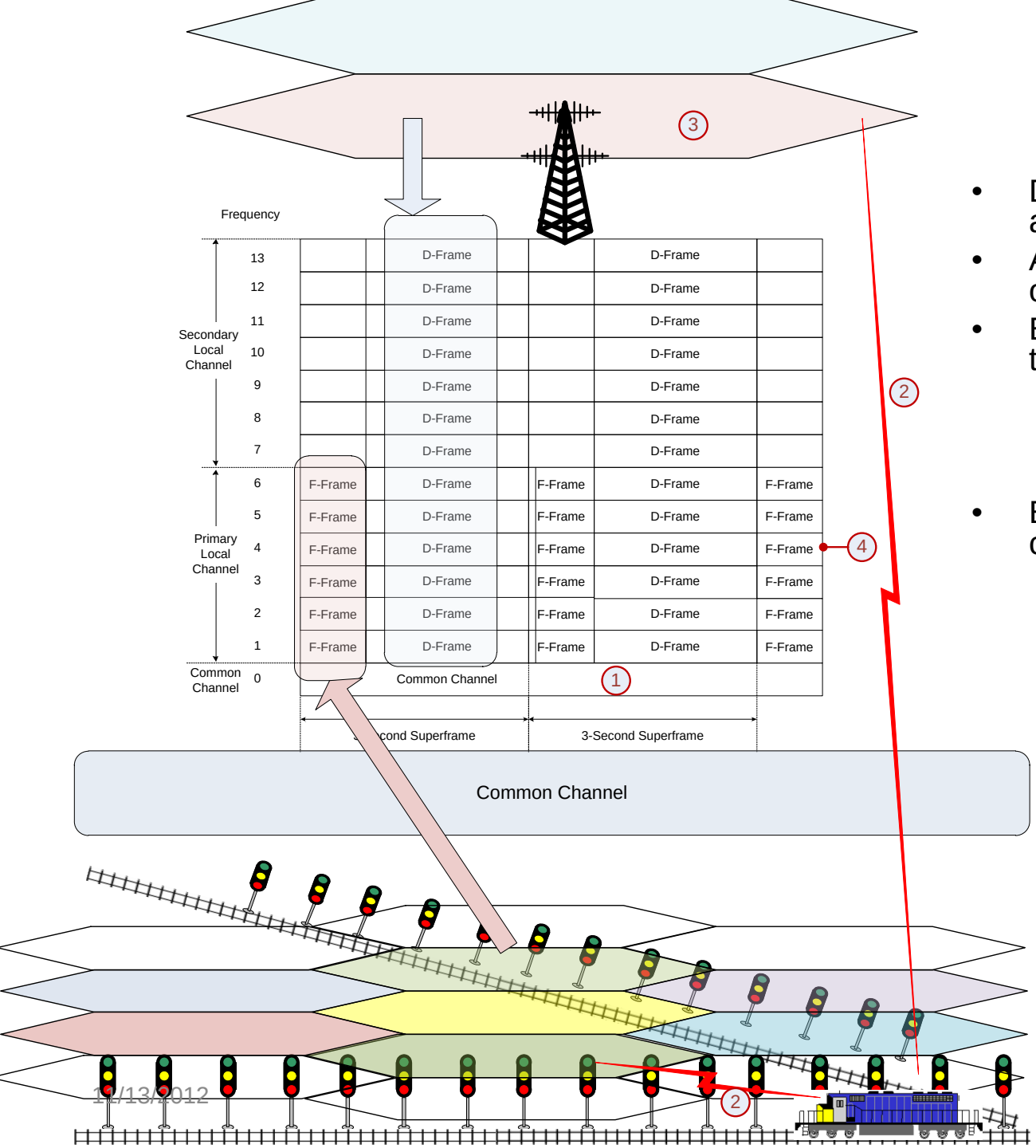
Wayside Slot Planning





Base/Loco Rx Channels	Base 1
1	F1
2	F2
3	F3
4	F4
5	F5
6	F6
7	F7

Base/Loco
- 1 Base channel
- 6 Neighbor channels



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Network Design Principles

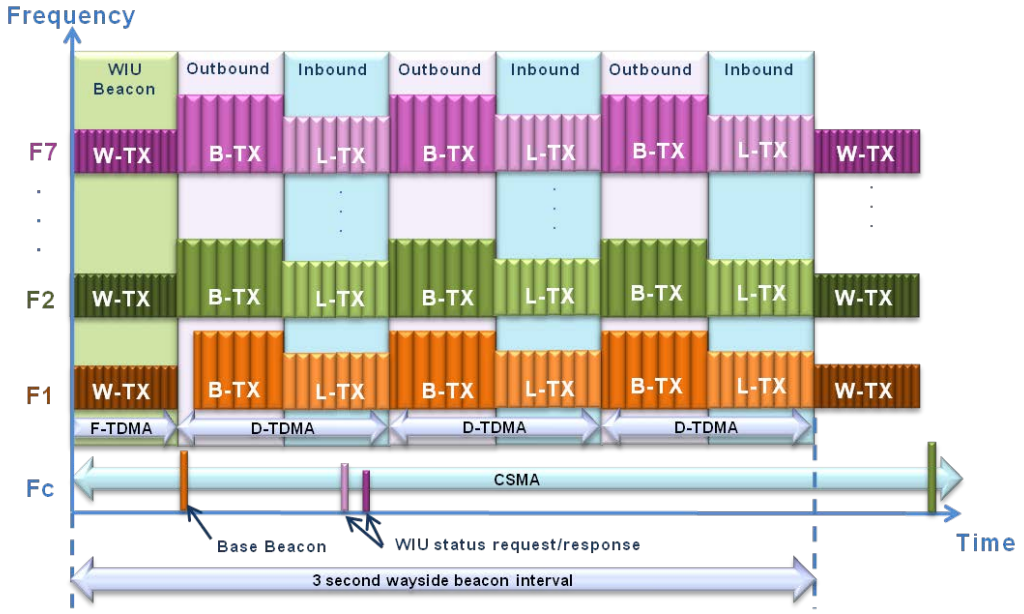
- Decouple base frequency planning and wayside slot planning
- All WIU status beacons are TX only in primary local channels
- Base/Loco radio RX channel tuning:
  - 1 Common ch
  - 6 Primary local ch
  - 1 Connected base local ch
- Base beacons are TX in local channels and common channel

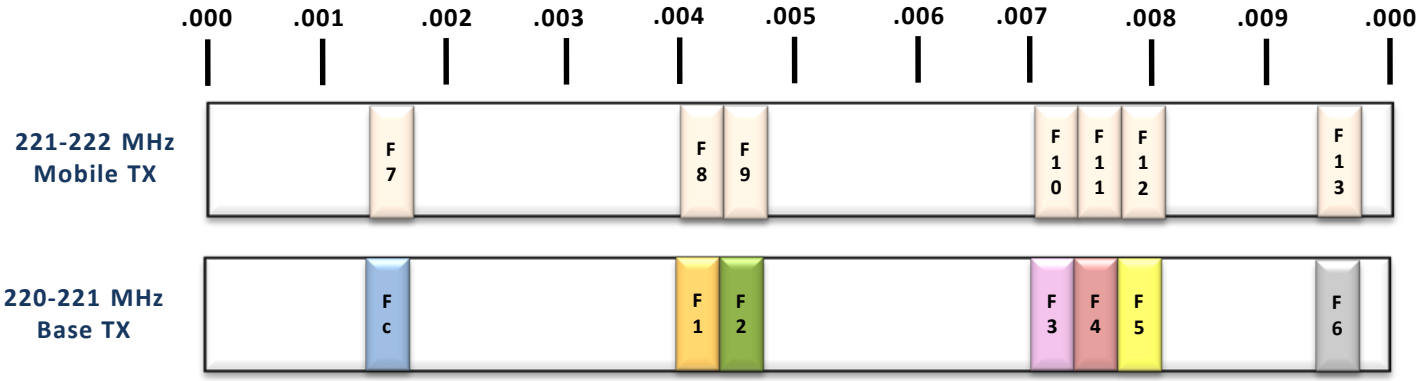
Network Design Steps

- Common channel selection
- Coverage planning
- Base frequency planning
- Wayside slot planning

Common Channel Selection

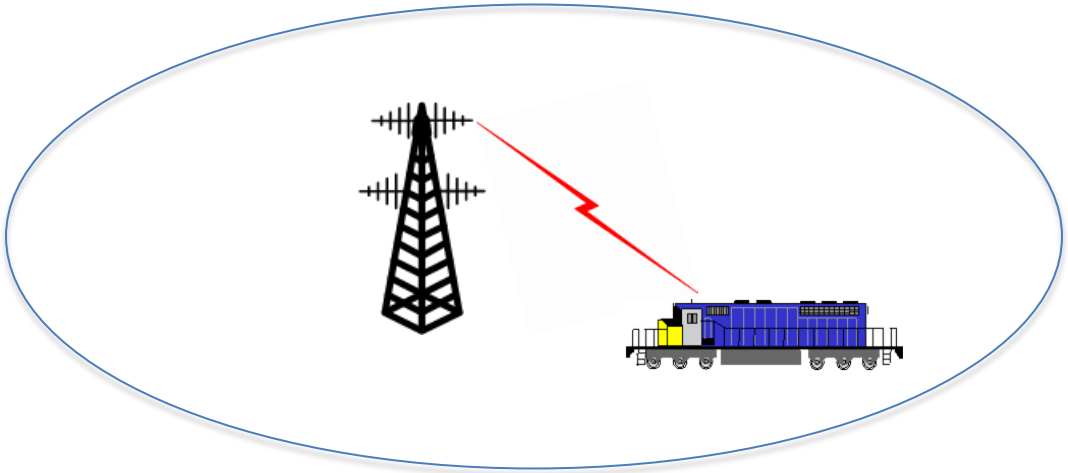
- Nationwide channel
- Base Tx frequency
- Low interference
  - Co-channel interference
  - Adjacent channel interference
  - Intermodulation interference



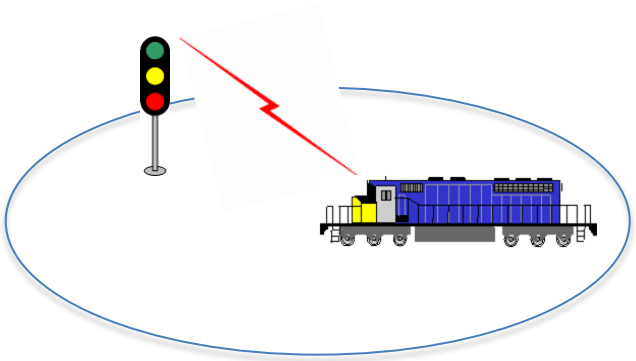


Coverage Planning

- Base Coverage
  - Base-Locomotive link budget

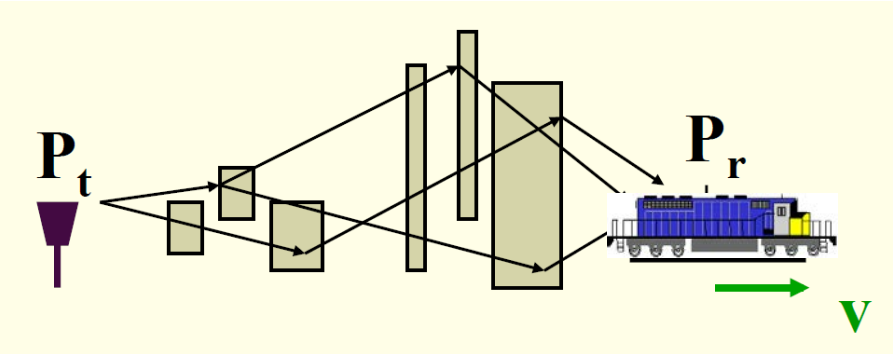


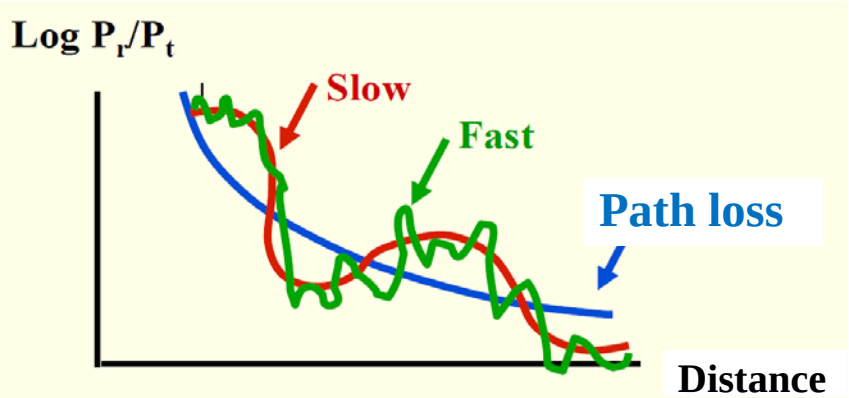
- Wayside Coverage
  - Wayside-Locomotive link budget



Propagation Characteristics

- Signal propagation over wireless channels





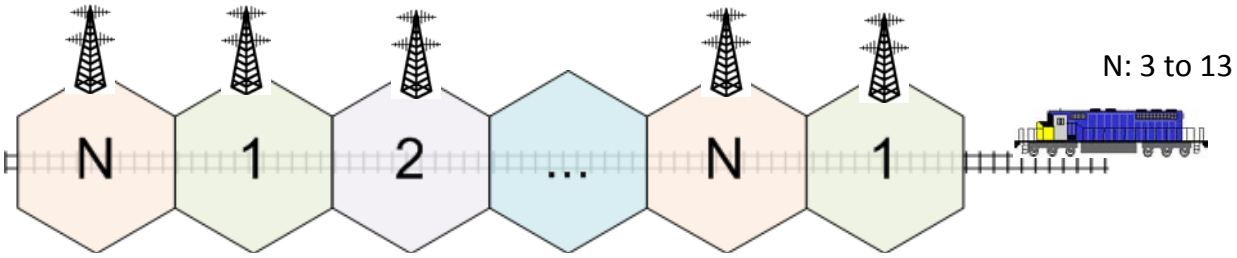
Three main components

- Path Loss
  - Signal loss over distance between the Tx and Rx
- Shadowing or slow fading (due to obstructions)
  - Log-normal distribution with standard deviation σ of 6 dB
- Multi-path Fading or fast fading

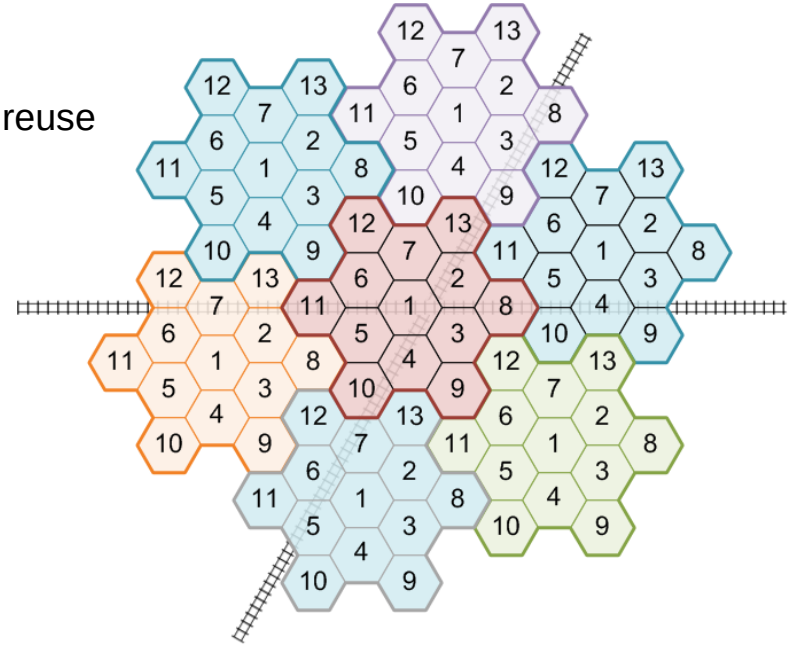
Channel Model (CM)	Environment	Description	Tap Number	Relative Delay (us)	Average Relative Power (dB)	Tap-gain process
CM1	Rural	Flat Rayleigh fading	1	0	0	Rayleigh
CM2	Urban	Frequency selective Rayleigh fading	1	0	0	Rayleigh
			2	15	-8.6	Rayleigh

Base Frequency Planning

- Assign frequency to each base for D-Frame communications
- Cellular frequency reuse scheme
- One dimension



- Two dimension: N= 3, 4, 7, 9, 13, …
  - 7 frequency reuse
  - 13 frequency reuse

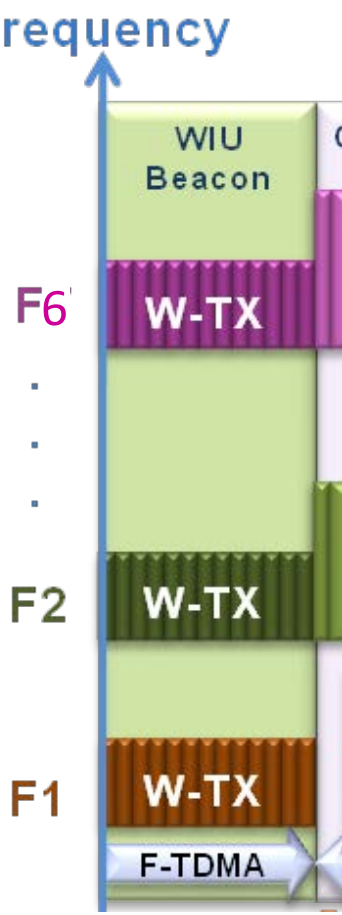


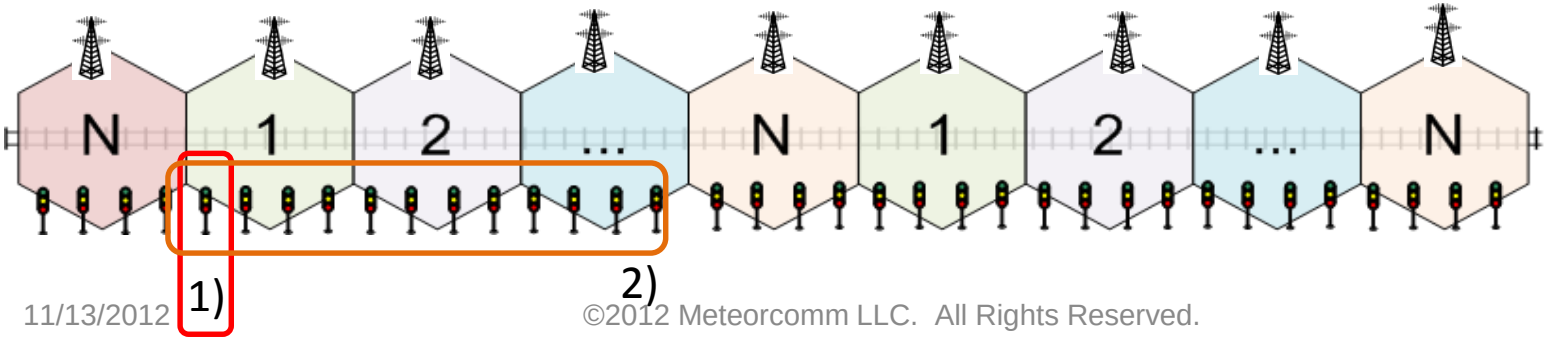
Wayside Slot Planning

1) Determine wayside slot size
- Vary based on size of device status
- Standard slot size can be used to simplify planning

2) Determine F-Frame size
- Vary with traffic
- Default value is 600ms, 1200 ms in high density area

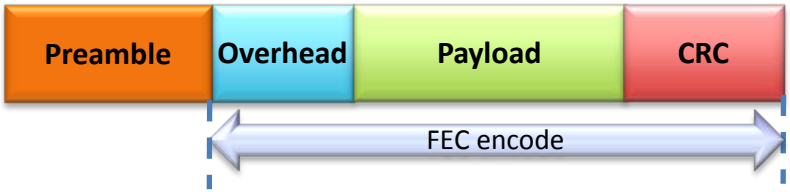
3) Allocate frequency and time slots for WIU messages (both direct and relay)
- Must ensure that locomotive receives WIU status of its approaching wayside
- Waysides in same area are tx on same channel (different time slot)
- Locomotive listens to all wayside tx channels





ITCnet Packet

- WIU Status



- Outbound/Inbound Data

- FEC Encoding
  - Code rate 0.75 - 4 bytes FEC per 12 bytes data

WIU Packet Size

EMP Header	12	Bytes
Bit rate	16	kbps
FEC rate	0.75	

	1	2	3	4	5	6	7	8	9	10
0	19	19	20	20	21	21	22	22	23	23
10	26	26	27	27	28	28	29	29	30	30
20	31	31	34	34	35	35	36	36	37	37
30	38	38	39	39	42	42	43	43	44	44
40	45	45	46	46	47	47	50	50	51	51
50	52	52	53	53	54	54	55	55	58	58
60	59	59	60	60	61	61	62	62	63	63
70	66	66	67	67	68	68	69	69	70	70
80	71	71	74	74	75	75	76	76	77	77
90	78	78	79	79	82	82	83	83	84	84
100	85	85	86	86	87	87	90	90	91	91
110	92	92	93	93	94	94	95	95	98	98
120	99	99	100	100	101	101	102	102	103	103
130	106	106	107	107	108	108	109	109	110	110
140	111	111	114	114	115	115	116	116	117	117
150	118	118	119	119	122	122	123	123	124	124
160	125	125	126	126	127	127	130	130	131	131
170	132	132	133	133	134	134	135	135	138	138
180	139	139	140	140	141	141	142	142	143	143
190	146	146	147	147	148	148	149	149	150	150
200	151	151	154	154	155	155	156	156	157	157
210	158	158	159	159	162	162	163	163	164	164
220	165	165	166	166	167	167	170	170	171	171
230	172	172	173	173	174	174	175	175	178	178
240	179	179	180	N/A	N/A	N/A	N/A	N/A	N/A	N/A

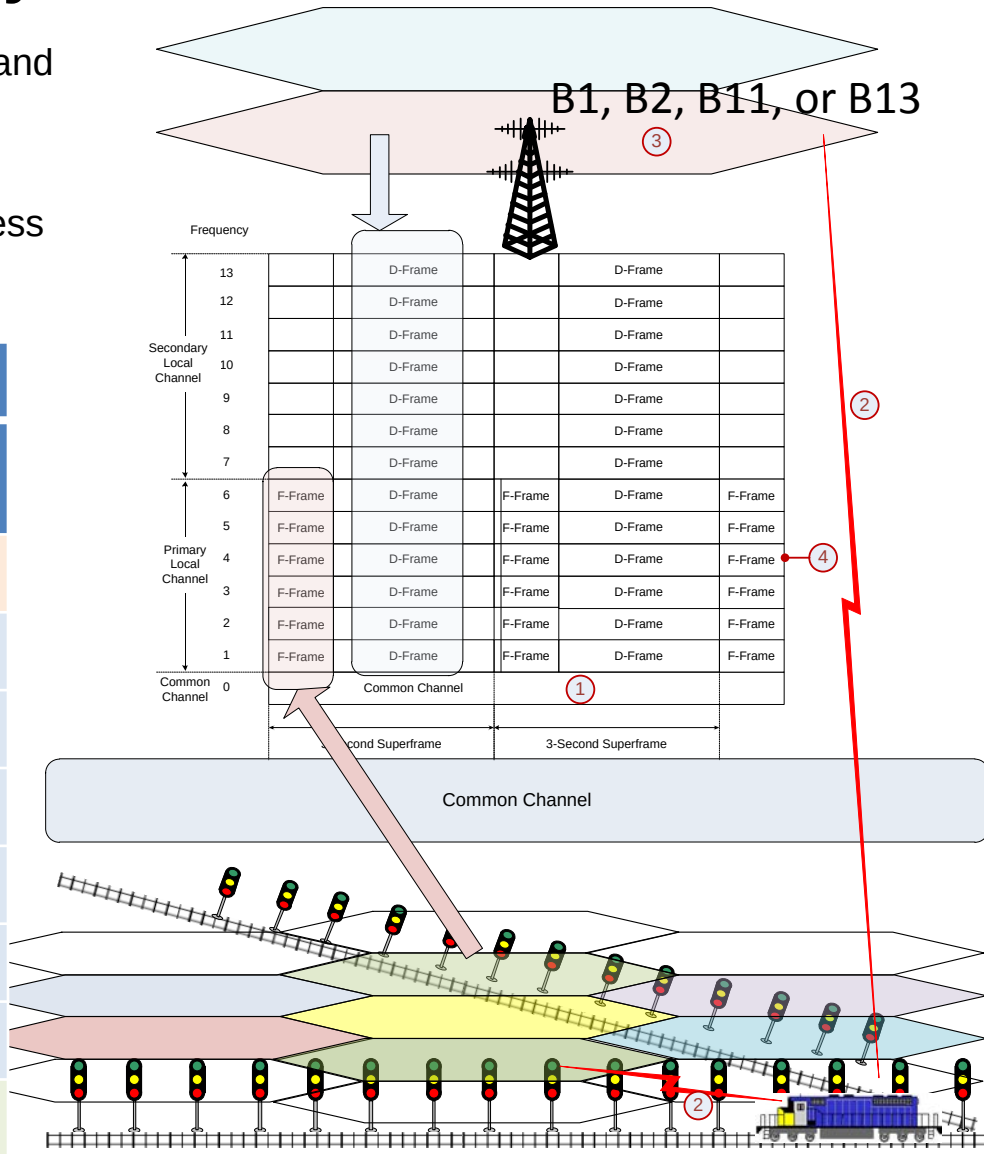
size of device status (bytes)

Packet size (ms)

Frequency Reuse – Fixed Wayside Beacon Channels

- All locomotive radios tune to same common channel and 6 wayside beacon channels
- Only connected base channels are different
- Locomotive listens to all wayside tx channels regardless of which base it connects to

Loco RX Channel	Connected Base			
	B1	B2	B11	B13
7	F1	F2	F11	F13
6	F6	F6	F6	F6
5	F5	F5	F5	F5
4	F4	F4	F4	F4
3	F3	F3	F3	F3
2	F2	F2	F2	F2
1	F1	F1	F1	F1
0	F0	F0	F0	F0



Wayside Slot Planning Results

- Wayside slot planning
  - Conduct slot planning
  - Output the slot plan

1	Slot plan			
2	Message ID	Channel_No	Offset_Time	Slot_Size
3	707643121005	126	0	30
4	707643121505	126	30	30
5	707643122005	126	60	30
6	707643120505	126	90	30
7	707643120506	126	120	30
8	707643120507	126	150	30
9	707643120005	126	180	30
10	707643122505	126	210	30
11	707643119506	126	240	30
12	707643119505	126	270	30
13	707643119507	126	300	30
14	707643123005	126	330	30
15	707643119005	126	360	30
16	707643118505	126	390	30
17	707643124005	126	420	30
18	707643116505	126	450	30

Summary

- Radio network overview with PTC system components and overview of ITC radio and protocol
- Network design principles overview with coverage planning, frequency planning, and wayside slot planning

Questions

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