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

Submission Title: [Proposal for FHSS PHY for 802.15.4k]
Date Submitted: [15 September 2011]
Source: [Matt Johnson] Company [Itron]
Address [2111 N Molter RD, Liberty Lake, WA 99019, USA]
Voice:[+1 509-891-3364], FAX: [+1 509-891-3896], E-Mail:[matt.johnson@itron.com]
Re: [Response to CFP issued 23 July 2011]

Abstract: [This document describes a FHSS PHY that addresses the requirements of the 802.15.4k PAR]

Purpose: [Proposal for consideration of inclusion into 802.15.4k standard.]

Agenda

- Architectural Drivers
- Operational Parameters
- PHY Parameters
- Link Budgets
- PHY Services
- MAC Enhancements

Architectural Drivers

Typical Applications

- Wireless Sensor Networks
- Gas and Water Metering
- Grid Situational Awareness
- Water Leak Detection
- Infrastructure Monitoring

Performance Expectations

- Up to 20 Year Endpoint Battery Life
  - All the electronics, not just the radio
- Very Low Cost to Build Radio for Endpoint/Sensors
- Relatively Low Latency/Availability
  - ~5 minutes
- 99% Hourly Read Reliability
- High link budget to support up to 100k endpoints/coordinator
- Support for worldwide deployment

Architectural Drivers

- Long battery life
  - Minimize TX and RX time while maintaining read reliability and availability
- Low cost endpoints
- Processing
  - Accommodate computational capabilities of low power microcontrollers
- Inherent asymmetry
  - Coordinators see much traffic (and noise), but have more capability/adaptability/upgradeability
  - Endpoints have little capability and adaptability
- Low duty cycle endpoint transmissions
- Relatively small payloads

Why FHSS?

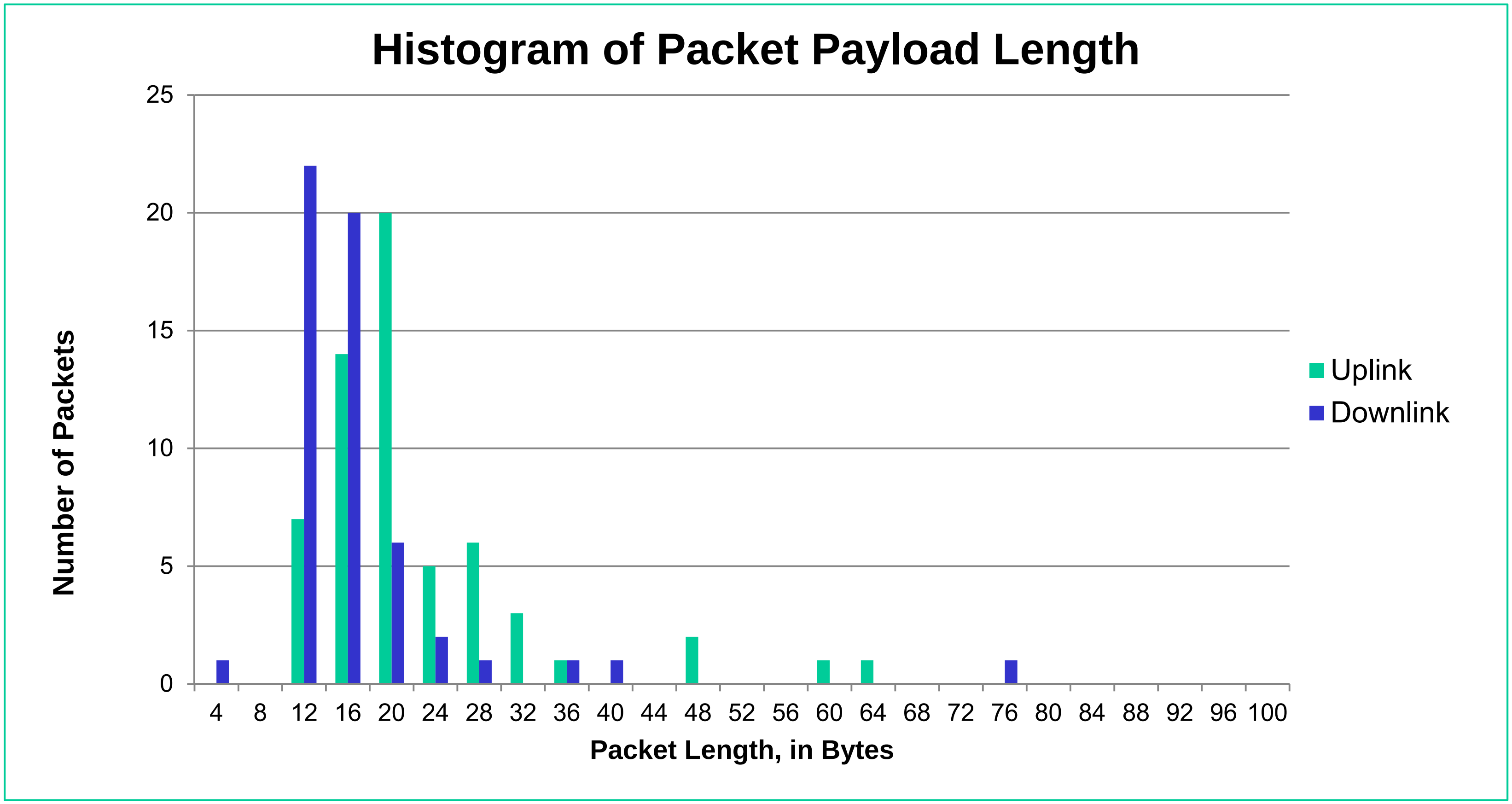
- Frequency Diversity
  - Effective for diversity reception
  - Provides greater degrees of freedom in coordinator receiver design for high capacity systems
  - Greater coordinator deployment flexibility
    - Single antenna on tower – lower cost
    - No tower-mounted electronics – high reliability
- Narrow-band FHSS has proven to have a high degree of interference immunity

Addressing Asymmetry

- First, in modulation
  - GFSK is proposed for uplink communications to reduce adjacent channel interference at coordinators (helps with near-far reception)
  - FSK is proposed for downlink communications to provide sharper decision points for low cost receivers in low cost endpoints
- Secondly, in data rate
  - Higher uplink data rate to maximize throughput for given channel coherence
  - Optional lower downlink data rate to accommodate processing limitations of low power microcontrollers

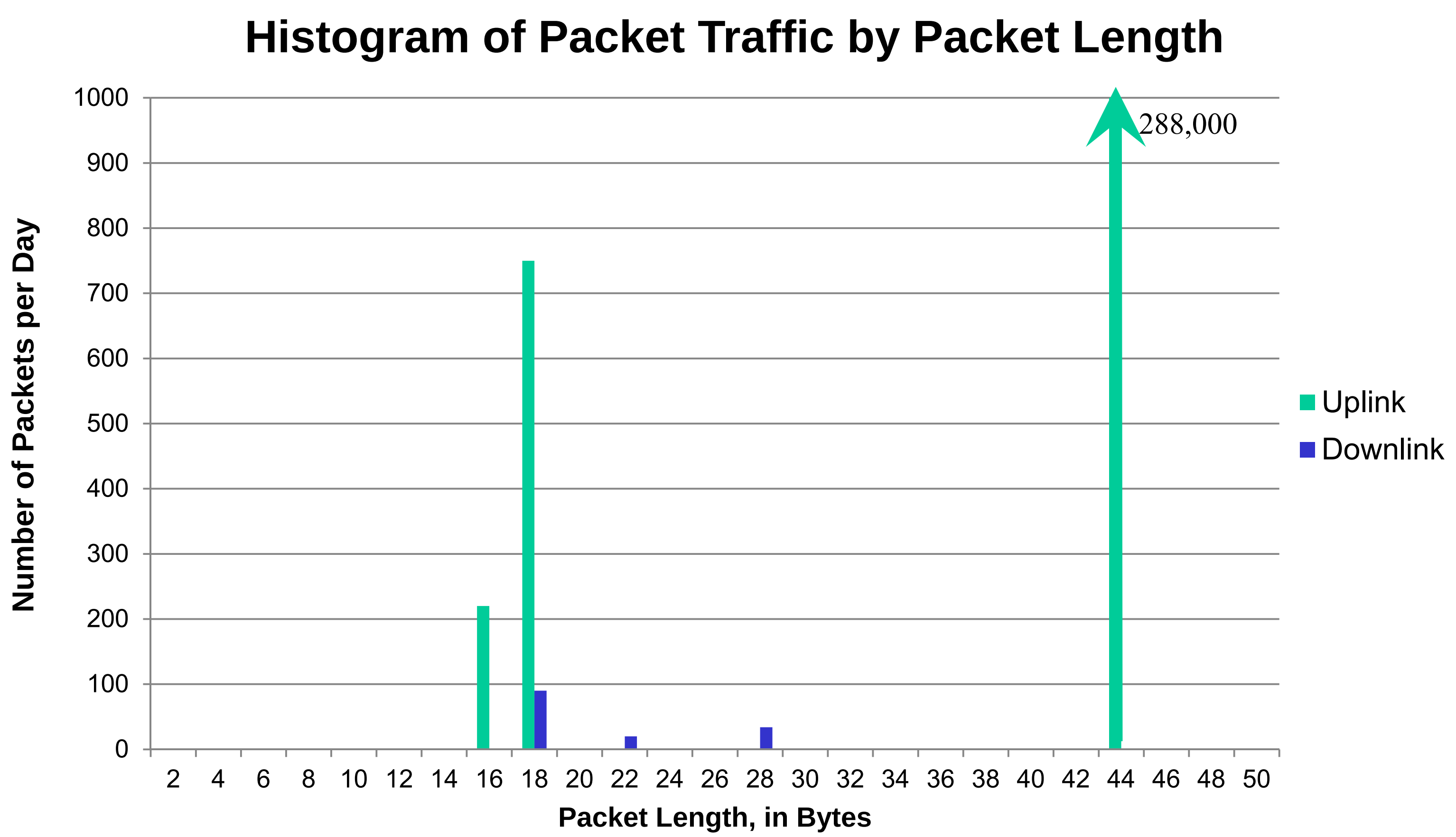
Operational Parameters

Typical Payloads from Gas/Water Metering



- Typical Operational Payloads are Relatively Small
- Fit well within 127 Octet *aMaxPHYPacketSize*

Daily Traffic on 1000 Endpoint System

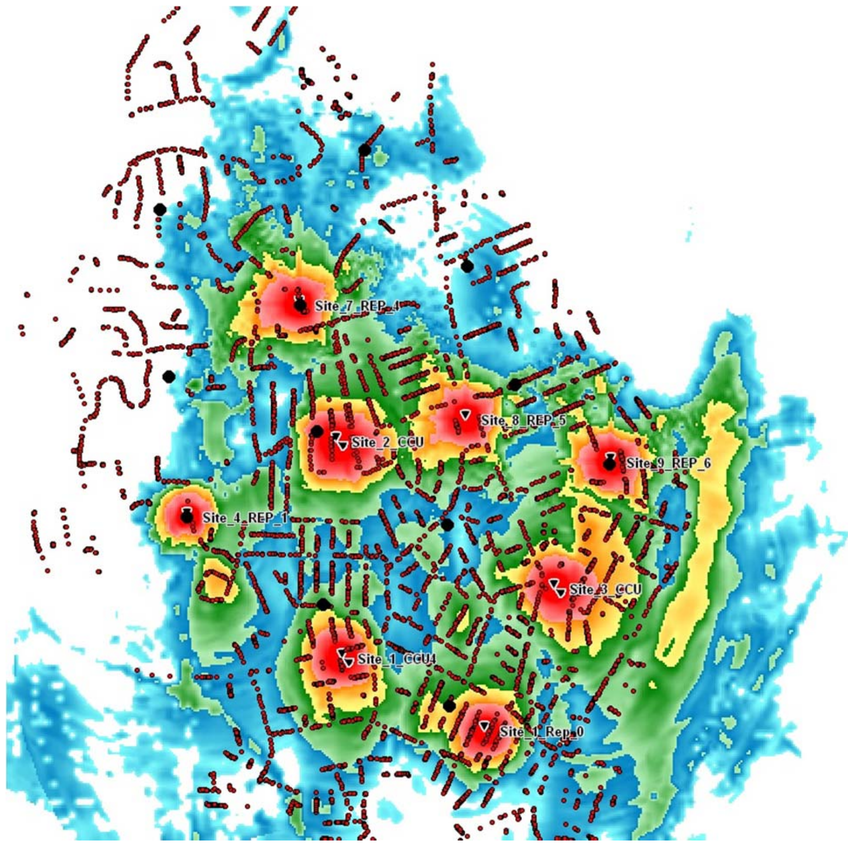


Coexistence with Other Radio Systems

- The targeted applications for 15.4k (15-11-245-02-004k) are generally characterized as low duty cycle applications
  - Typically < 0.1% duty cycle
- Most applications employ battery powered endpoints
  - Energy Detection impacts battery life
- Since 15.4k applications are quite low duty cycle, even without energy detection, they do not represent a coexistence concern to other systems

Typical LECIM Deployments

- Multiple Cells(Coordinators)
- Overlapping Coverage
- Large Scale
- Fixed Assignments of Endpoints to Coordinators is Problematic
- Need to manage multiple PANs as one network
  - Need for a Network Identifier in addition to existing PAN IDs and addressing modes



Network Operational Assumptions

- When operating as a non-beaconed network
  - Battery life can be maximized
  - Supports low duty cycle of applications
- 127 octet PHY payload is adequate
- Uplink traffic is:
  - Likely heard by multiple coordinators
  - Unacknowledged

Addressing

- Coordinator assigned,16 bit addressing is inadequate for the scale of LECIM deployments
- Addressing needs to support entire network not just one coordinator's PAN
- Need for a Network ID across coordinators
  - Programmed in endpoints at installation
- Uplink:
  - Use 64 bit source address and Network ID
- Downlink:
  - Use 64 bit source and destination address

Error Detection/Correction

- Use of a 32 bit CRC is recommended
  - 16 bit CRCs are inadequate in star networks with >1000 endpoints per collector
  - Probability of bad packets passing as good is too high with the 16 bit CRC

Channel Coherence

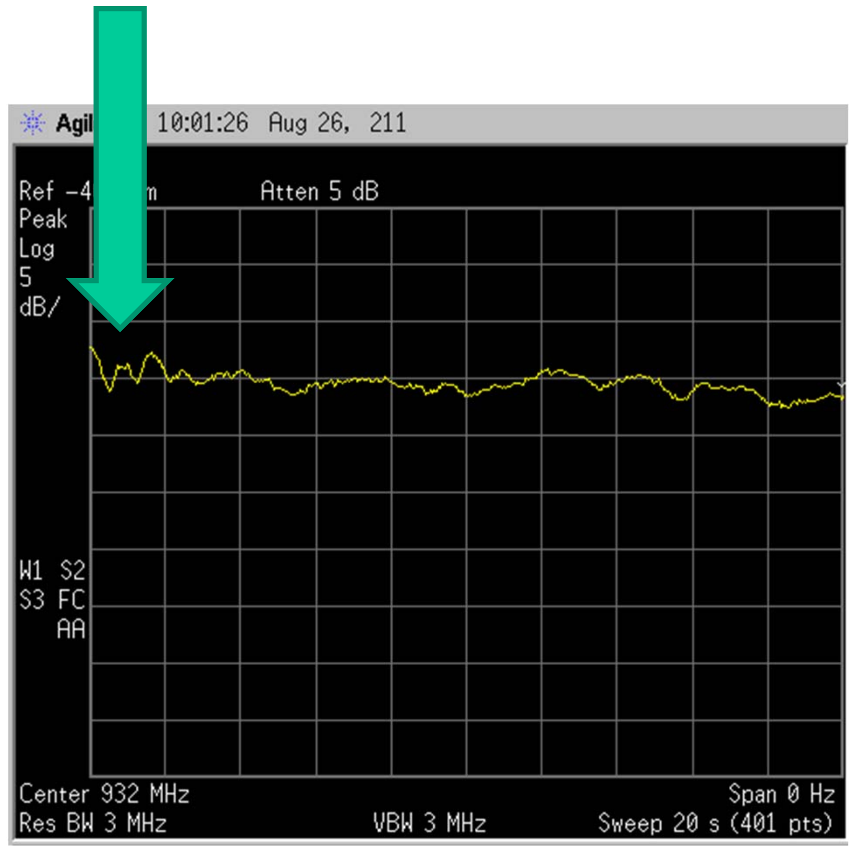
- Based on measured PSR (in the real world):
  - In the 915 MHz band, we estimate channel coherence at 18 to 20 ms
- Interference
  - In 915 ISM there are a wide variety of non-standards-based systems
- Ricean fading environment

Fading - Arterial Road with LOS

- 5 lane road
- Moderate traffic
- 55 km/hr speeds

- Fading ≤ 5-7 dB

Semi tractor-trailer across the street

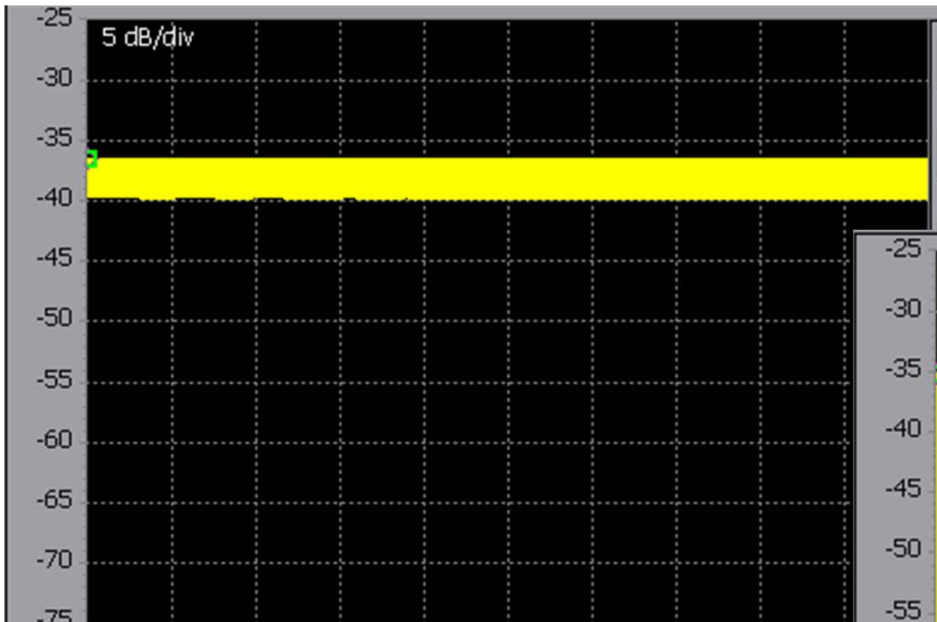


Excerpted from 15-11-0593-00-004k

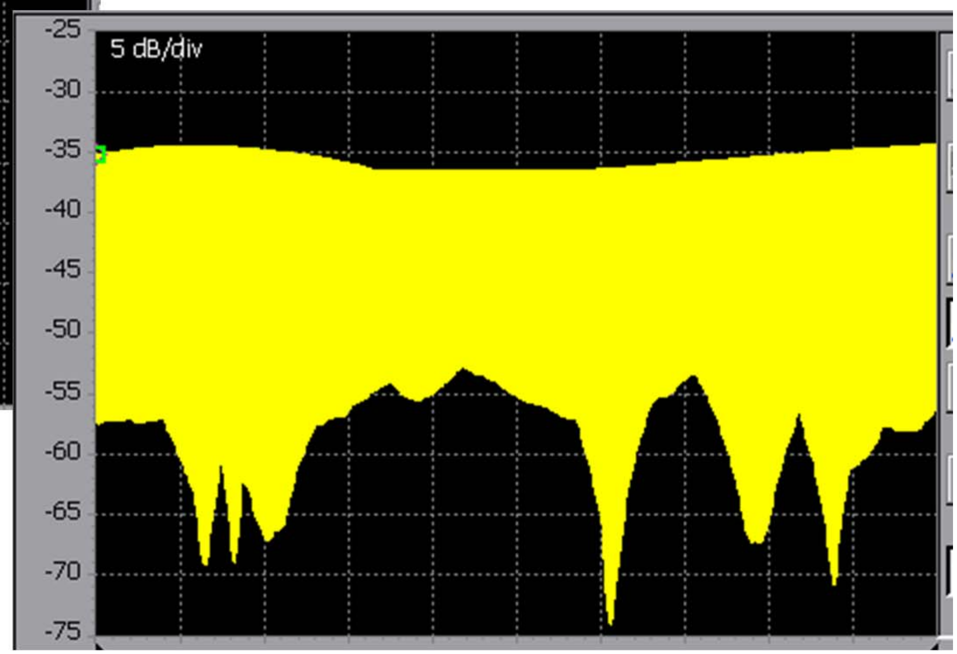
Stationary versus Mobile Fading

Max/Min Hold Power Envelope – Arterial Road

Stationary – 3 to 4 dB of Fading
Candidate for Ricean Fading Model



~ 5 km/hr – up to 40 dB of fading
Candidate for Rayleigh Fading Model



Most (All?) LECIM Applications (15-11-0245-02-004k) are stationary

PHY Parameters

Factors in selecting data rates

- PAR dictates < 40 kbps
- Option to provide a path to 15.4g compatibility
- Option to maintain highest reasonable rate to maximize use of available channel coherence time
- Option for a downlink data rate that can be supported in low computing-power endpoints
- Avoid precluding (implementer specific) battery optimizations, such as on-air rate detection used to reduce RX on-time

Data Rate for 4g Compatibility

- The lowest 15.4g MR-FSK rate, of 50 kbps, is common for 868, 915, and 2450
- Provide a data rate option in 4k that is one-half of the 50 kbps in 15.4g that could be easily included in 15.4g coordinators
- 25 kpbs is one option for data rate in this proposed 4k PHY

Additional Data Rate Options

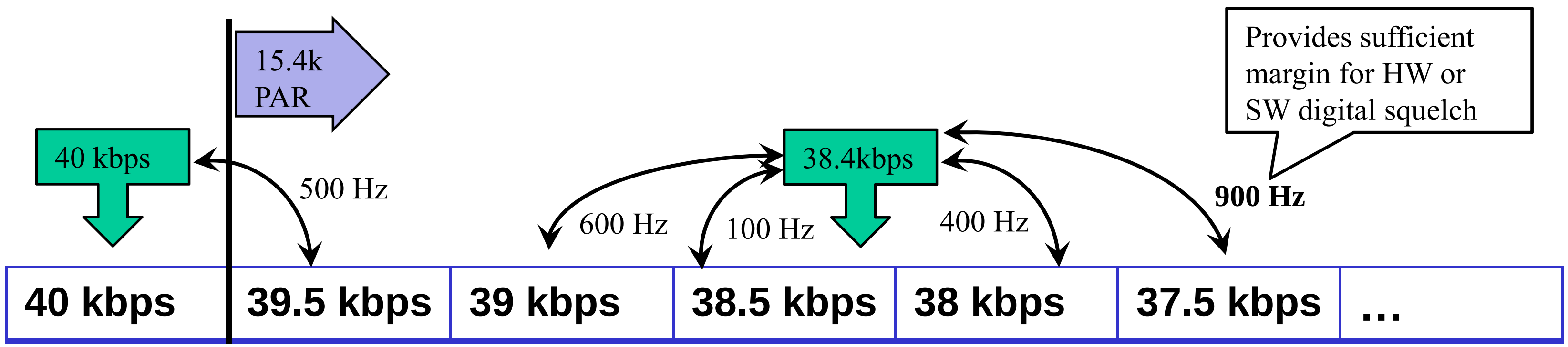
- With 25 kbps as a starting point:
  - Add an option at 37.5 kbps to optimize use of channel coherence time
  - Add an option at 12.5 kbps to support downlinks to low-compute-power endpoints

15.4g	50 kbps	4g MR-FSK
15.4k	37.5 kbps	Maximum Data Rate Option
	25 kbps	4g Compatibility Option
	12.5 kbps	Low Computing Power Endpoint Option

On-Air Data Rate Detection

- Detection of on-the-air data rate by endpoint to reduce RX on time (also known as “digital squelch”)
  - Faster approach to detection of potential traffic for endpoint than preamble detection and addressing alone
  - If detection of the desired data rate occurs, then further decoding proceeds, otherwise receiver is turned off
- Data rate needs to be chosen far enough away from other on-air data rates to reduce falsing for both HW and SW approaches to on-air rate detection
  - Some common on-air rates for GFSK/FSK include 38.4 kbps and 40 kbps, such as:
    - SCADA/Telemetry
    - Serial Extension radios
    - Numerous Short Range Wireless modules
    - Z-Wave®

On-Air Data Rate Detection



PHY Parameters Summary

200 kHz channel spacing			
900 MHz: US, Japan, Korea 868 MHz, 2.4 GHz	37.5 kbps	GFSK	Maximum Data Rate Option
	25 kbps	GFSK	4g Compatibility Option
Low Rate Downlink	12.5 kbps	FSK	Low Computing Power Endpoint Option

US 915 MHz ISM Parameters

- Channels
  - 129 Channels
  - $Freq_0$ =902.2
- Channel Spacing of 200 kHz
- Data Rate
  - Uplink 37.5/25 kbps GFSK
  - Downlink 37.5/25/12.5 kbps FSK
- Modulation Index

	Uplink	Downlink
37.5 kbps	0.5	0.5
25 kbps	1.0	1.0
12.5 kbps	4.0	

Japan 920 MHz SUN Parameters

- Channels
  - 15 Channels
  - $Freq_0$ = 920.6
- Channel Spacing of 200 kHz
- Data Rate
  - Uplink 37.5/25 kbps GFSK
  - Downlink 37.5/25/12.5 kbps FSK
- Modulation Index

	Uplink	Downlink
37.5 kbps	0.5	0.5
25 kbps	1.0	1.0
12.5 kbps	4.0	

Korean USN Parameters

- Channels
  - 32 Channels
  - $Freq_0$ = 917.1
- Channel Spacing of 200 kHz
- Data Rate
  - Uplink 37.5/25 kbps GFSK
  - Downlink 37.5/25/12.5 kbps FSK
- Modulation Index

	Uplink	Downlink
37.5 kbps	0.5	0.5
25 kbps	1.0	1.0
12.5 kbps	4.0	

Europe 868 MHz SRD Parameters

- Channels
  - 34 Channels
  - $Freq_0$ = 863.125
- Channel Spacing of 200 kHz
- Data Rate
  - Uplink 37.5/25 kbps GFSK
  - Downlink 37.5/25/12.5 kbps FSK
- Modulation Index

	Uplink	Downlink
37.5 kbps	0.5	0.5
25 kbps	1.0	1.0
12.5 kbps	4.0	

Global 2450 MHz Parameters

- Channels
  - 416 Channels
  - $Freq_0$ = 2400.2
- Channel Spacing of 200 kHz
- Data Rate
  - Uplink 37.5/25 kbps GFSK
  - Downlink 37.5/25/12.5 kbps FSK
- Modulation Index

	Uplink	Downlink
37.5 kbps	0.5	0.5
25 kbps	1.0	1.0
12.5 kbps	4.0	

Link Budgets

915 MHz Link Budget

Channel Model Parameters		Notes
Frequency (MHz)	915	Valid Range 150-2400 MHz
Collector Antenna Height (m)	30	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	1	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	3	Valid Range 1-20 km

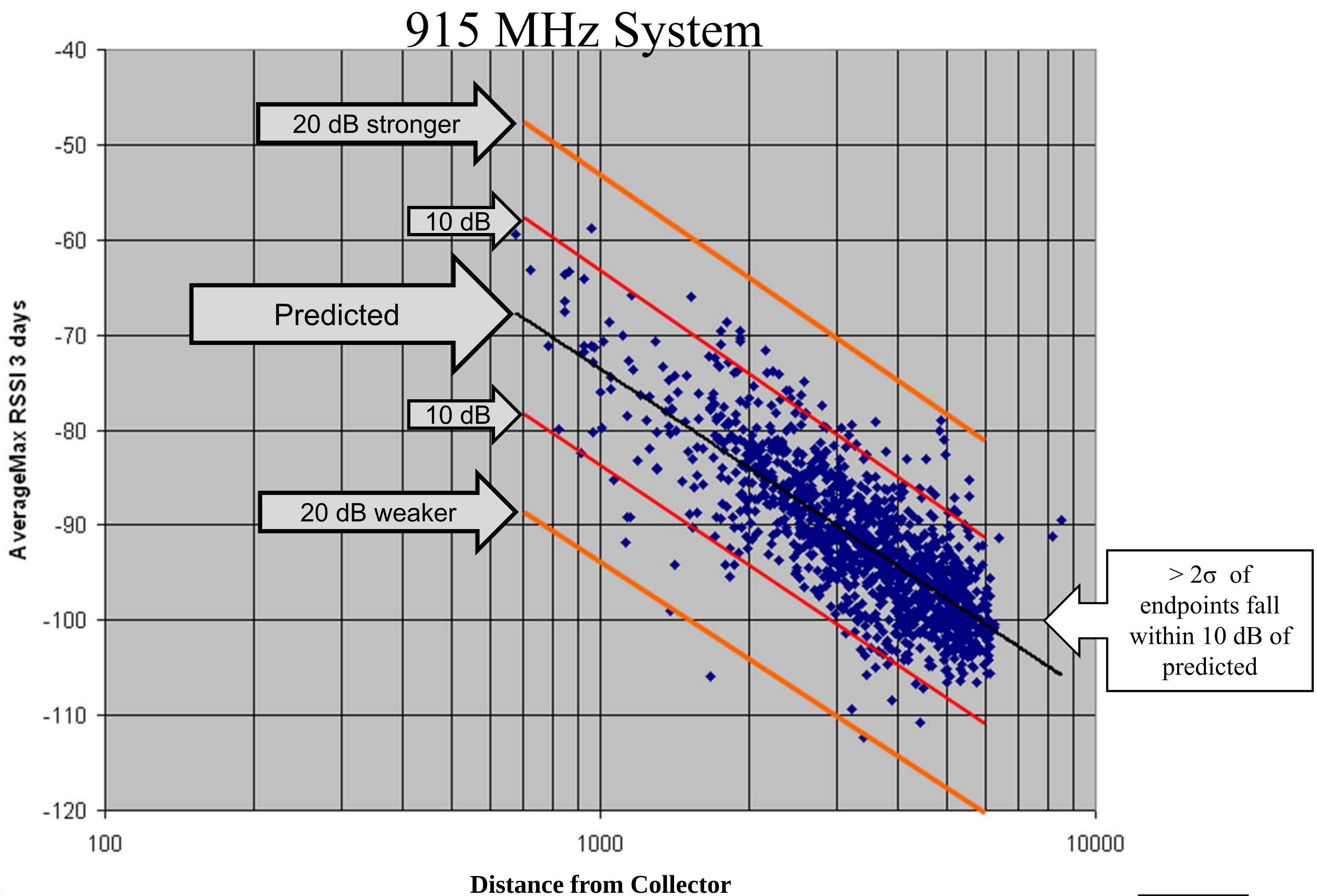
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	30	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	6	Subject to Tx Power Regulations
Path Loss (dB)	-134.73	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-10	To buffer against variable shadowing loss
Penetration Loss (dB)	0	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	2	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	**-105.73**	Compare against Rx sensitivity

Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	27	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	2	Subject to Tx Power Regulations
Penetration Loss (dB)	0	For underground vaults, etc.
Path Loss (dB)	-134.73	Same as Downlink
Shadowing Margin (dB)	-10	Same as Downlink
Collector Rx Antenna Gain (dBi)	6	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	**-107.73**	Compare against Rx sensitivity

Based on multiple network deployments

No single number can adequately describe penetration loss, there are options for mitigation an installation

Measured Shadowing Effect



920 MHz Japanese SUN Link Budget

Channel Model Parameters		Notes
Frequency (MHz)	920	Valid Range 150-2400 MHz
Collector Antenna Height (m)	30	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	1	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	2	Valid Range 1-20 km

Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	24	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	3	Subject to Tx Power Regulations
Path Loss (dB)	-128.58	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-10	To buffer against variable shadowing loss
Penetration Loss (dB)	0	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	2	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	**-108.58**	Compare against Rx sensitivity

Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	24	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	2	Subject to Tx Power Regulations
Penetration Loss (dB)	0	For underground vaults, etc.
Path Loss (dB)	-128.58	Same as Downlink
Shadowing Margin (dB)	-10	Same as Downlink
Collector Rx Antenna Gain (dBi)	3	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	**-107.58**	Compare against Rx sensitivity

917 MHz Korean USN Link Budget

Channel Model Parameters		Notes
Frequency (MHz)	920	Valid Range 150-2400 MHz
Collector Antenna Height (m)	30	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	1	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range 1-20 km

Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	10	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-117.97	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-10	To buffer against variable shadowing loss
Penetration Loss (dB)	0	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	**-116.97**	Compare against Rx sensitivity

Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	10	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	0	For underground vaults, etc.
Path Loss (dB)	-117.97	Same as Downlink
Shadowing Margin (dB)	-10	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	**-115.97**	Compare against Rx sensitivity

868 MHz Link Budget

Channel Model Parameters		Notes
Frequency (MHz)	868	Valid Range 150-2400 MHz
Collector Antenna Height (m)	30	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range 1-20 km

Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	14	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	2.15	Subject to Tx Power Regulations
Path Loss (dB)	-115.11	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-10	To buffer against variable shadowing loss
Penetration Loss (dB)	0	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	2.15	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	**-105.81**	Compare against Rx sensitivity

Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	14	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	2.15	Subject to Tx Power Regulations
Penetration Loss (dB)	0	For underground vaults, etc.
Path Loss (dB)	-115.11	Same as Downlink
Shadowing Margin (dB)	-10	Same as Downlink
Collector Rx Antenna Gain (dBi)	2.15	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	**-104.81**	Compare against Rx sensitivity

2450 MHz Link Budget

Channel Model Parameters		Notes
Frequency (MHz)	2400	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range 1-20 km

Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	30	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	6	Subject to Tx Power Regulations
Path Loss (dB)	-123.61	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-12	To buffer against variable shadowing loss
Penetration Loss (dB)	0	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	2	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	**-96.61**	Compare against Rx sensitivity

Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	27	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	2	Subject to Tx Power Regulations
Penetration Loss (dB)	0	For underground vaults, etc.
Path Loss (dB)	-123.61	Same as Downlink
Shadowing Margin (dB)	-12	Same as Downlink
Collector Rx Antenna Gain (dBi)	6	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	**-98.61**	Compare against Rx sensitivity

PHY Services

Network Management Support

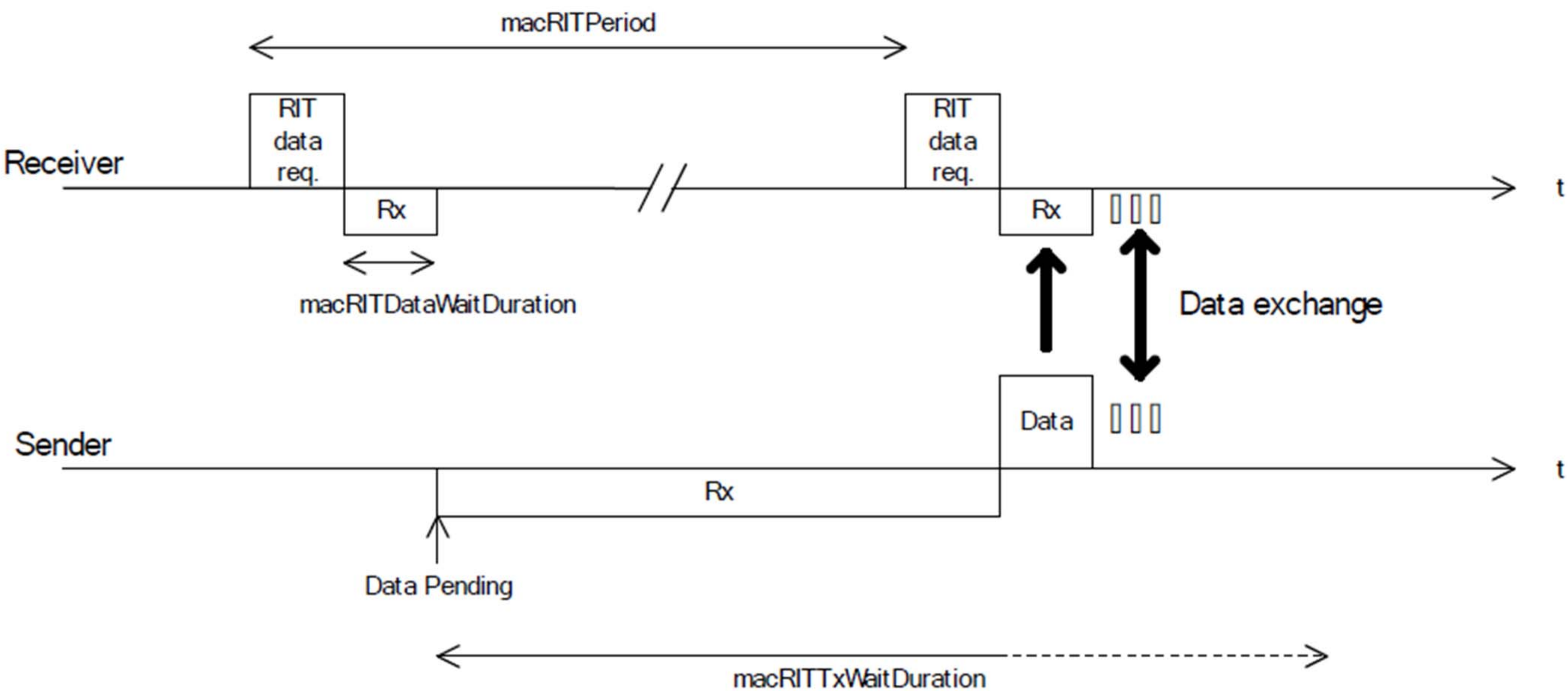
- There is a need to gauge channel quality to avoid using “bad” channels and support network management
- To support this:
  - MAC shall monitor and log good and bad packet decodes per channel at coordinator (Channel identification provided by PHY)
  - PHY shall be able to measure and log channel noise at the coordinator
  - PHY shall be able to report LQI of decoded packets
    - Want a higher resolution indicator such as 2 dB steps of RSSI to support >120 dB link budget requirement

MAC Enhancements

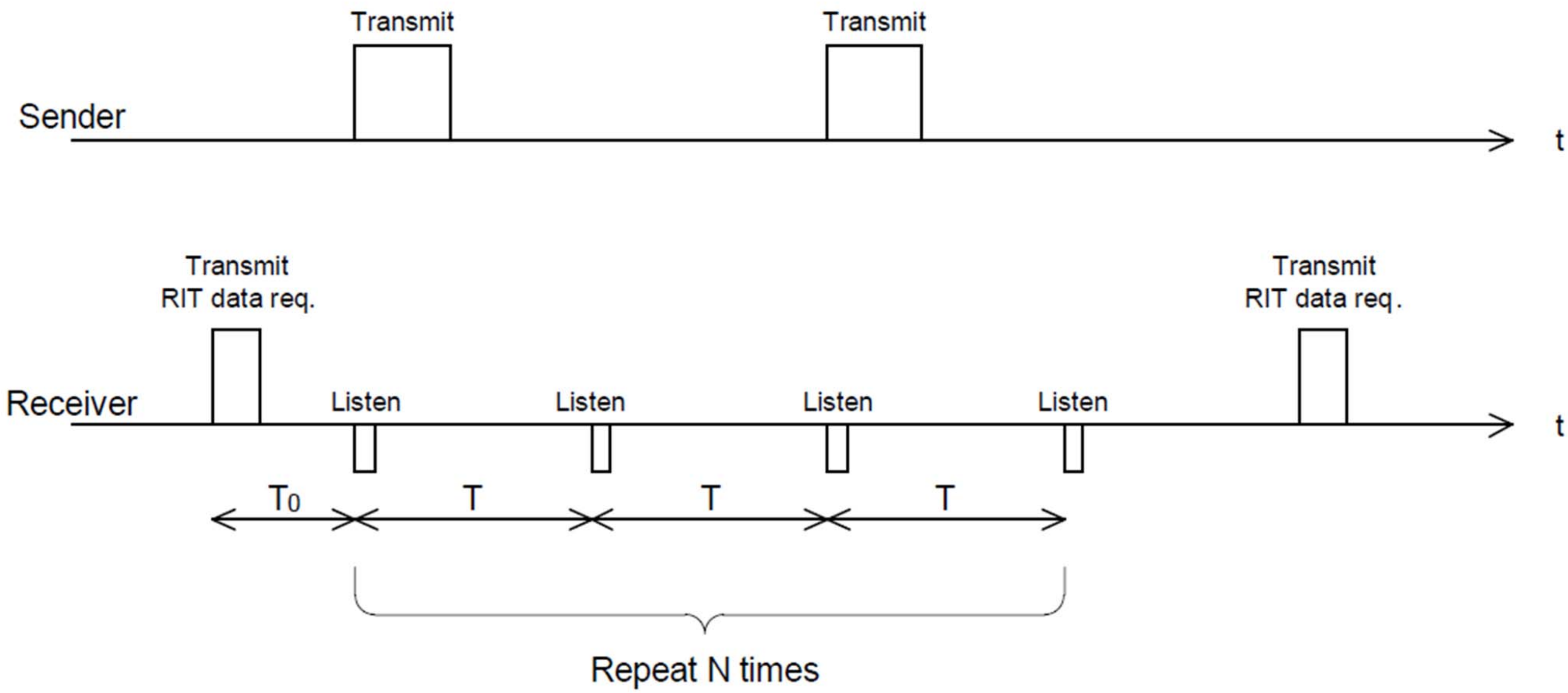
Implicit RIT

- 15.4e MAC enhancements add valuable flexibility like RIT, but sensors aren't always smart enough to know when to ask if there is data queued on the coordinator for them, but we want some guarantee of availability
- Adding extra RIT transmissions to query for data reduces battery life
- Implicit RIT turns on the endpoint receiver once after each transmission (not just a RIT packet) to enable reception of data from the coordinator
- With professional installation, all endpoints are programmed with system-wide defaults at installation.

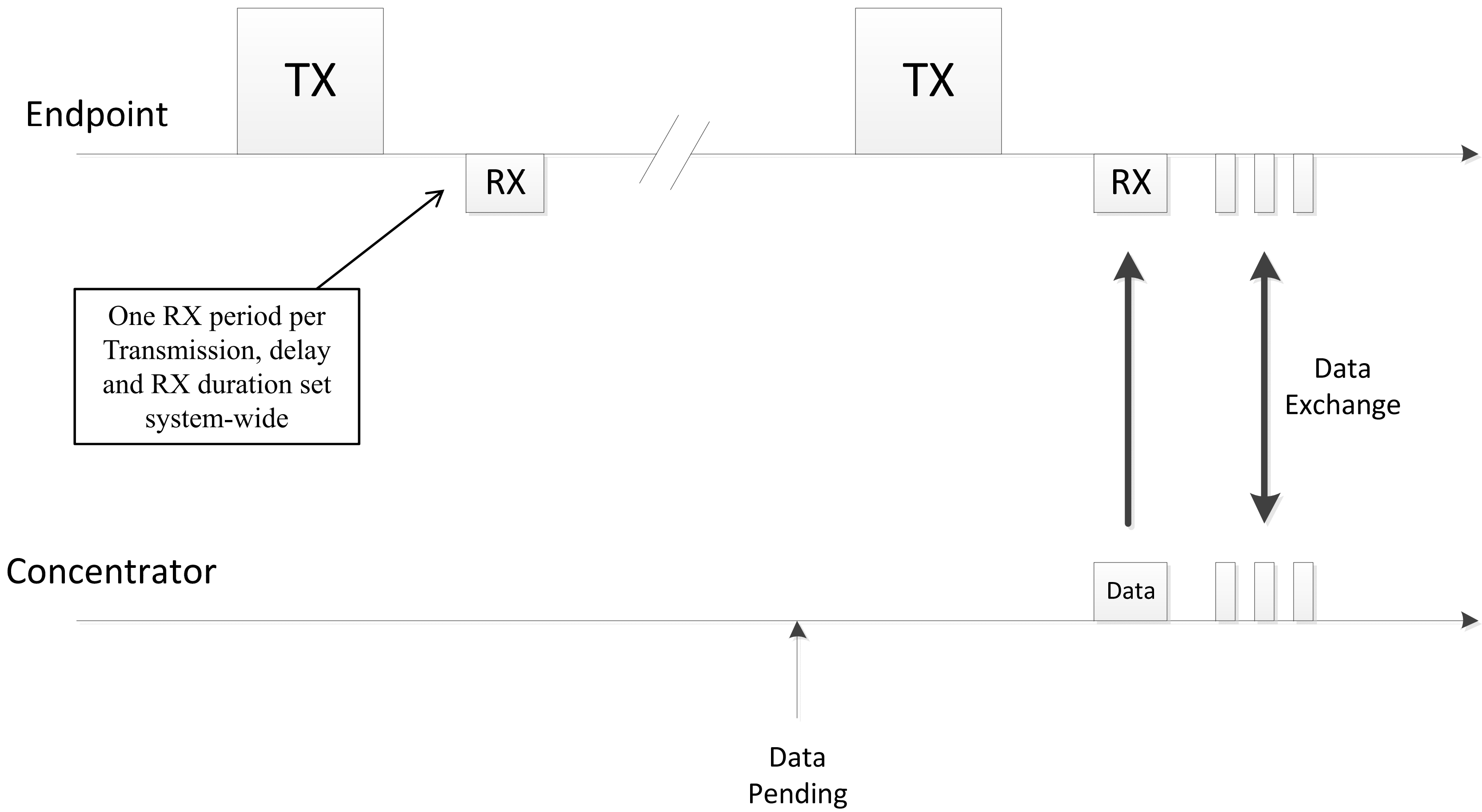
Receiver Initiated Transmission (RIT)



RIT


Transmit
Transmit
Sender
t
Transmit
RIT data req.
Transmit
RIT data req.
Receiver
Listen
Listen
Listen
Listen
t
T0
T
T
T
Repeat N times

I-RIT


Endpoint
TX
TX
RX
RX
One RX period per Transmission, delay and RX duration set system-wide
Data Exchange
Concentrator
Data
Data Pending

Summary

- Low duty cycle, largely unacknowledged endpoint operation to maximize battery life
- Coexistence supported by low duty cycle and frequency hopping
- Addressing and management across multiple PANs as a single network
- Implicit-RIT enhancement to enhance battery operation
- Data Rate and Modulation options to support maximizing channel coherence, 15.4g compatibility and low-computing power endpoints

Thank You!