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RPMA

Technology Overview

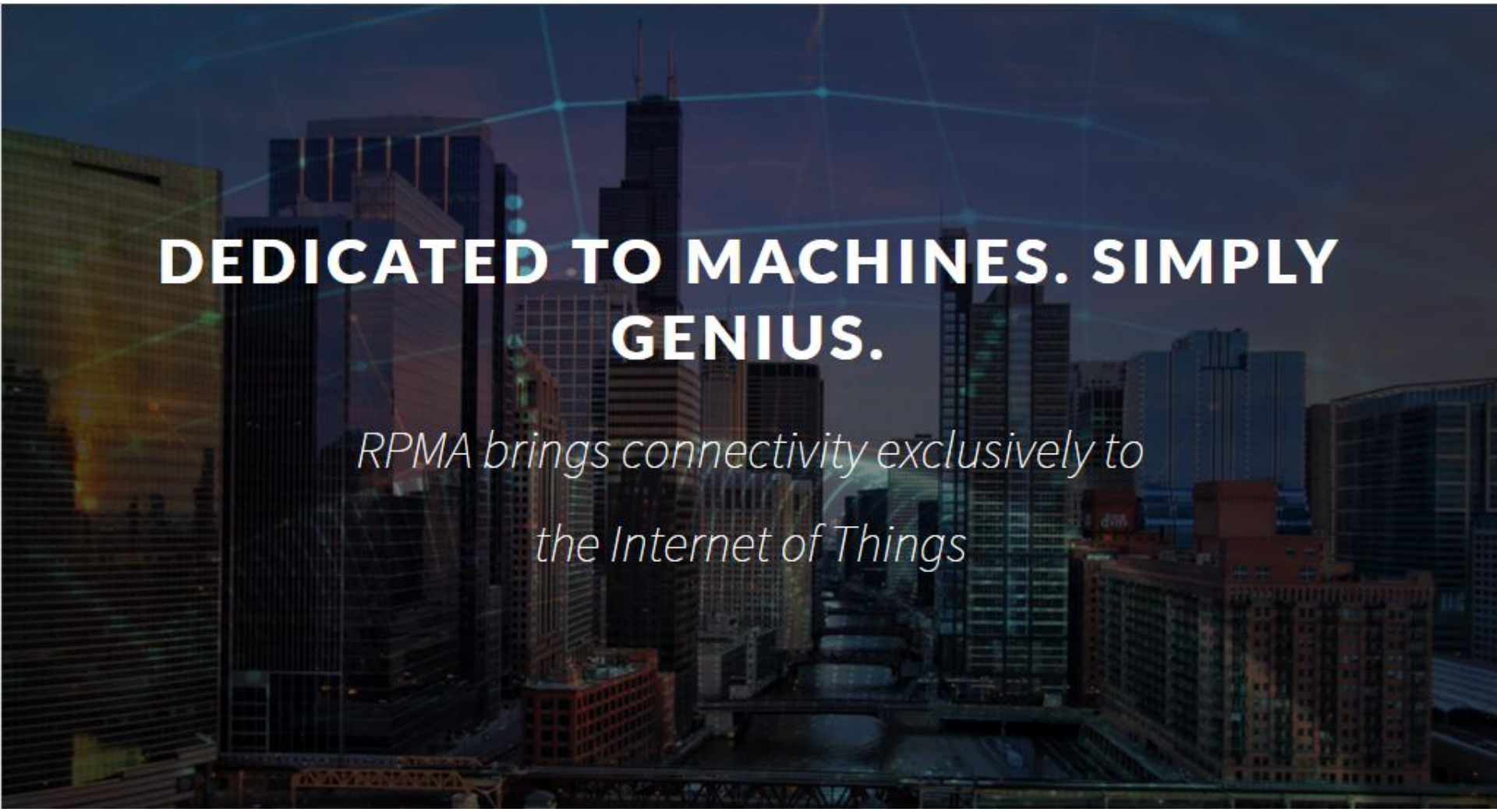
09/28/2015

simply genius

RPMA Technology Overview Agenda

- Network Planning
- Physical Layer 2.1
- Medium Access Control 2.1
- Network Operations
- RPMA Solution Architecture
- End-Points and Applications

RPMA


DEDICATED TO MACHINES. SIMPLY GENIUS.
RPMA brings connectivity exclusively to the Internet of Things

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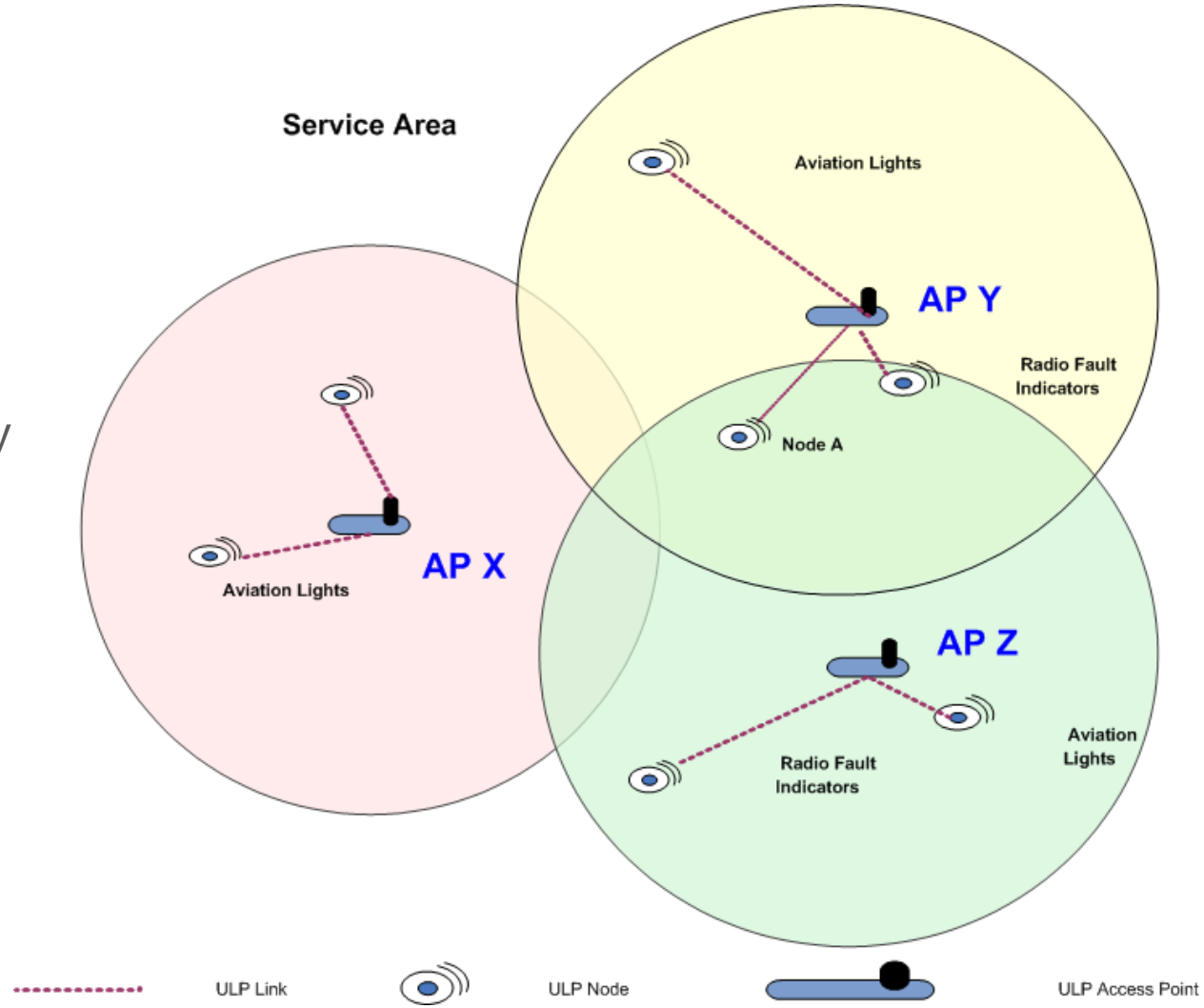
Network Planning

Network Planning – Star Topology

- Each AP cell can support up to 64k devices.
- Overlapping Coverage Desired
  - AP Macro Diversity
  - Redundancy
- Rectangular grid spacing of AP's is ideal.



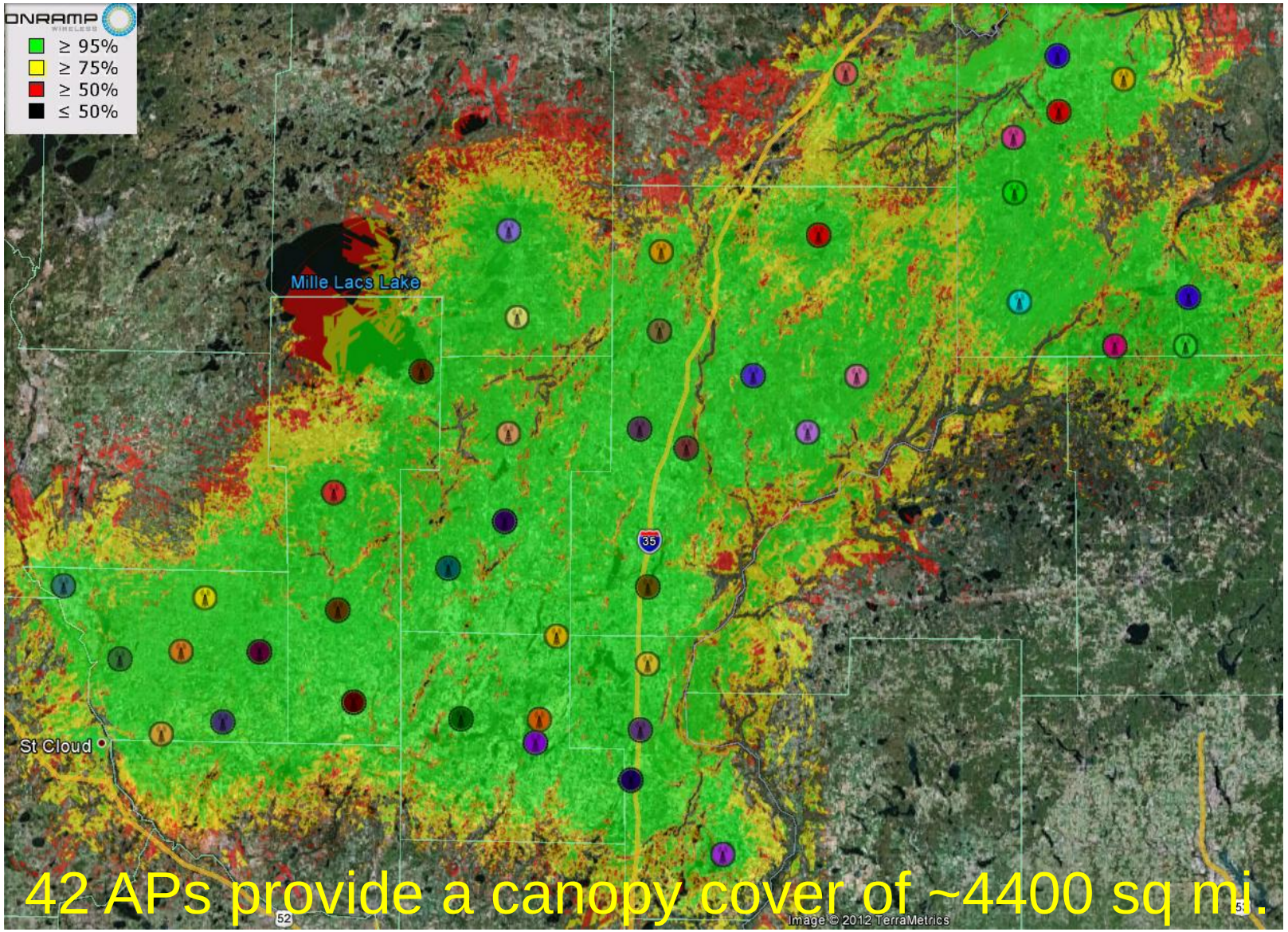
Network Planning – Importance Of

- Sets coverage expectations
  - Give a very high degree of confidence of coverage
  - Considers Terrain, Clutter, Margin, Interference, AP Macro Diversity, end-point antenna diversity and install scenarios.

- Sets quality of service (QOS) expectations
  - Reliable Delivery Rates
  - Latencies
  - Battery Life Expectations
  - A properly designed network maximizes these benefits

- Foundation of deployment planning
  - Provides guidance as to where to deploy Access Points.
  - May factor into wireless backhaul design.

Network Planning – Example Coverage Map



42 APs provide a canopy cover of ~4400 sq mi.

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Network Planning – Prerequisites

- Inputs from Network Operator
  - Private network model
    - Asset locations (e.g. meters, transformers, vault locations) or geographic region to cover.
    - Candidate AP sites (e.g. comm towers, building tops, utility poles).
    - Service Expectations (99.9% vs. 98.5% delivery rates)
  - Public network model
    - Service territory definitions
    - Depth of service requirements and expectations.
    - Tower vendor asset lists

- End-point Install Characteristics
  - Device configuration (e.g. antenna diversity enabled).
  - Indoor/Outdoor
  - Installation height/type
    - Ground level, over-head, underground, or pad-mount
    - Metal device enclosure

Network Planning – Outputs

- Coverage maps
  - Summary Power Point Presentation (inputs and assumptions used)
  - Maps in Google Earth kmz format.

- 2.4 GHz frequency plan and re-use code assignments
  - General ISM interference mitigation.
  - Coordinated compatibility with other RPMA networks.

Physical Layer 2.1

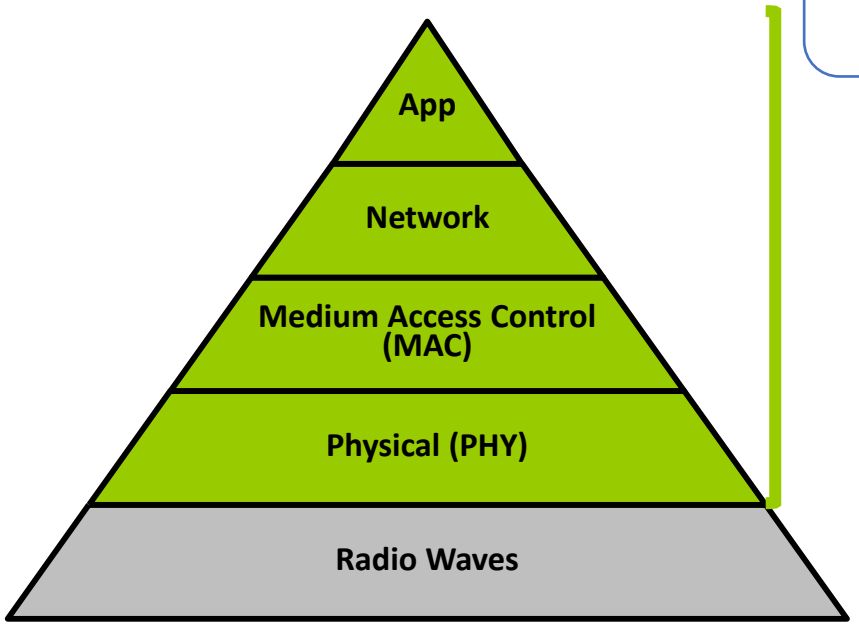
We Took a Different Approach

- Starting over from the foundation…..

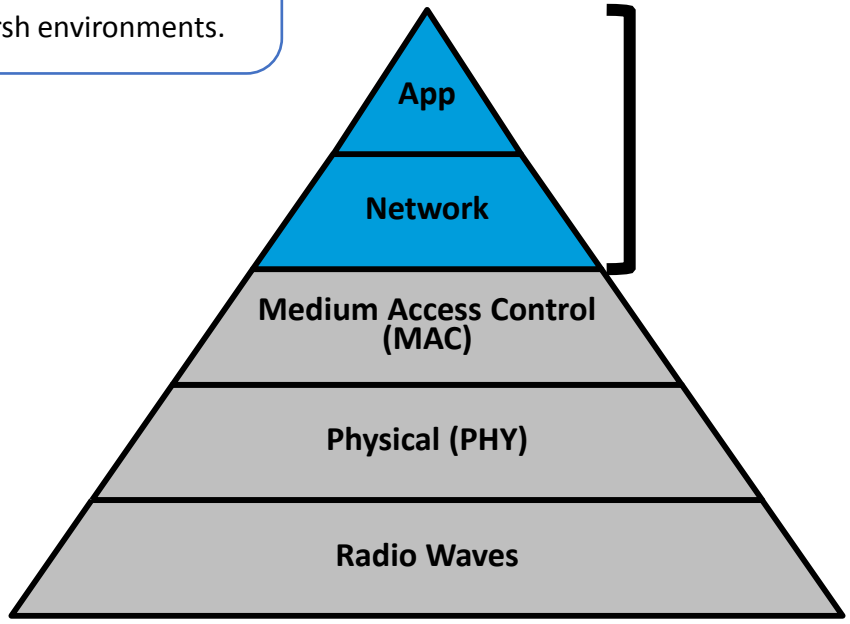
Ingenu Technology Approach

- **15 Patents Awarded**
- **23 Patents In Process**

Purpose-built for long range, reliable wireless communications in harsh environments.



The competition has limited latitude to optimize a communications solution



Typical Competitor's Approach

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Physical Layer – Key Features

- Link Budget
  - An exceptional 172 dB link budget gives deployment options
  - Large coverage area per AP (above ground assets)
  - High signal penetration for RF disadvantaged enclosures

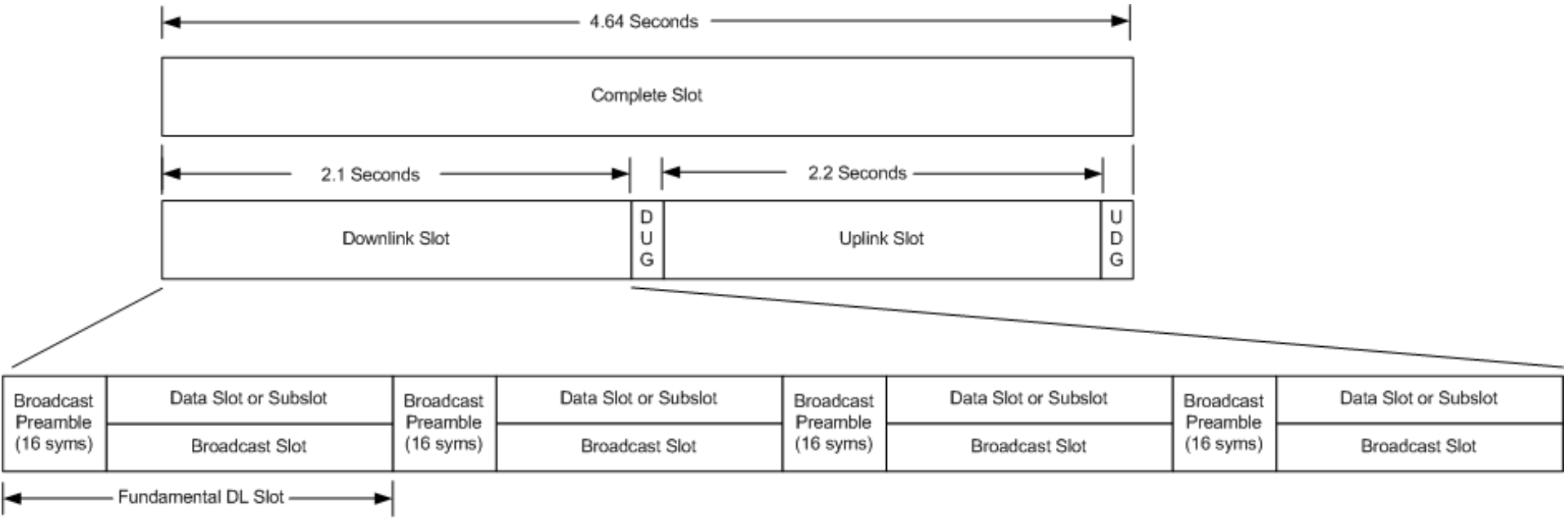
- High Capacity
  - RPMA allows for 1200 UL PDU packets **per frame**.
  - Aggregate UL data rate of 100 MB/day.

Physical Layer – Key Features (cont'd)

- Uplink (UL)
  - Differential BPSK, Direct Sequence Spread Spectrum
  - AP Rx Sensitivity -142 dBm
  - Processing gain of up to 39 dB

- Downlink (DL)
  - Orthogonal Differential BPSK, Direct Sequence Spread Spectrum.
  - Node Rx Sensitivity -133 dBm
  - Processing gain of up to 33 dB

Physical Layer – Basic Frame Structure

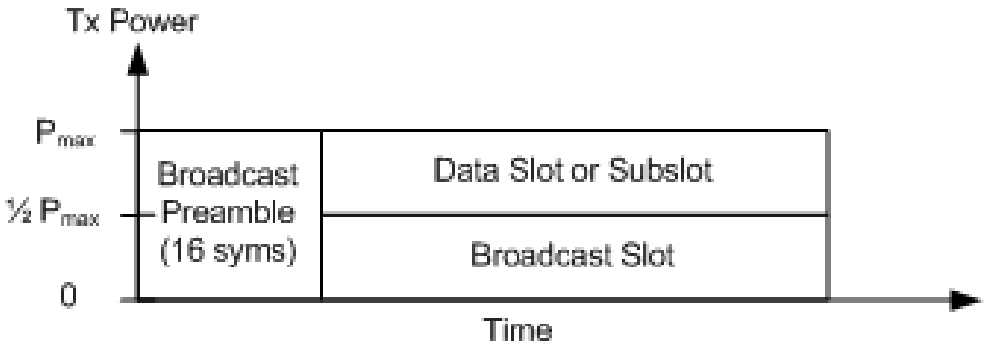


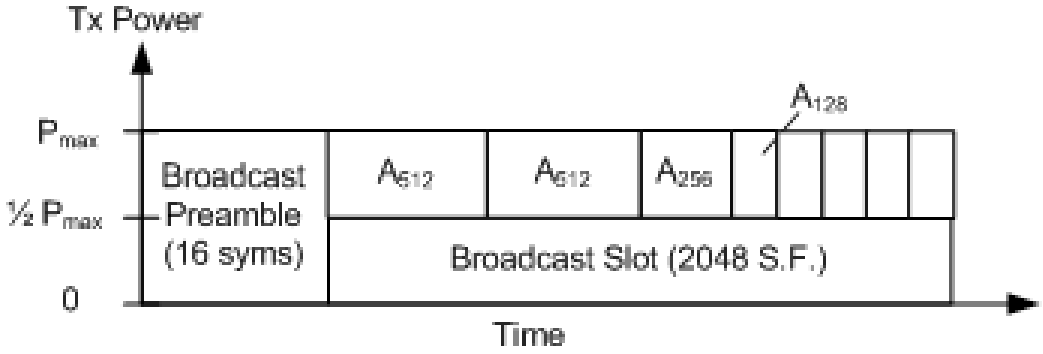
Assuming a Maximum UL Spreading Factor of 8192
Maximum DL Spreading Factor is 2048.
UDG – Uplink to Downlink Gap, 1 Symbol x 8192 Chips
DUG – Downlink to Uplink Gap, 38 Symbols x 8192 Chips

- Frame Structure is continuous and deterministic
- 18600 frames per day.
- UL and DL is Time Division Multiplexed (TDM)

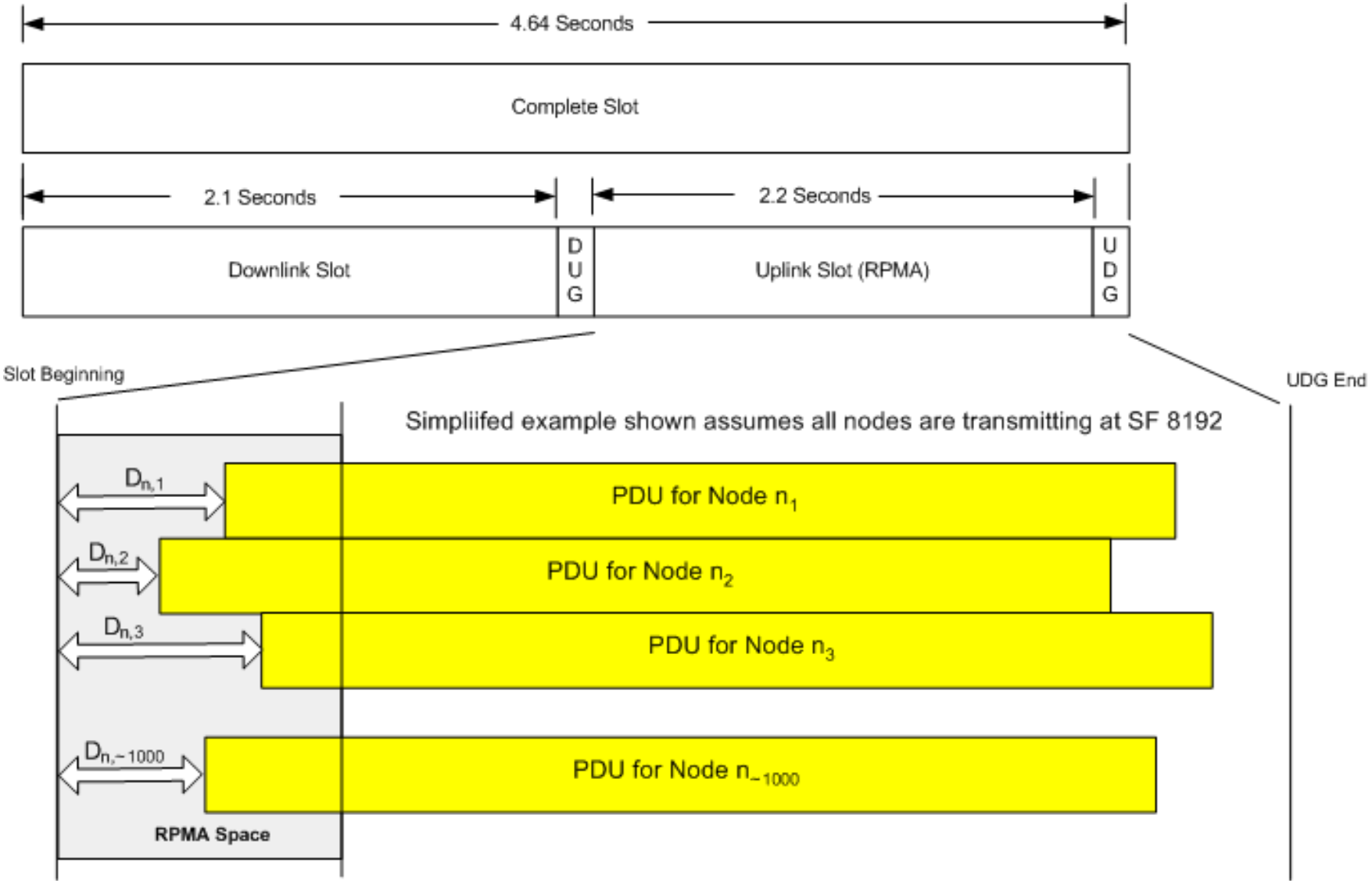
Physical Layer – Downlink Frame Structure

- Comprises 4 Fundamental Slots, Time Division Multiplexed
- Fundamental Slot comprises a Preamble, a Broadcast Channel, and a Data Channel.
- Preamble power is +3 dB boosted relative to either BCH or DCH.
- Spreading Factor Determines PDU transmit duration





Physical Layer – Uplink Frame Structure

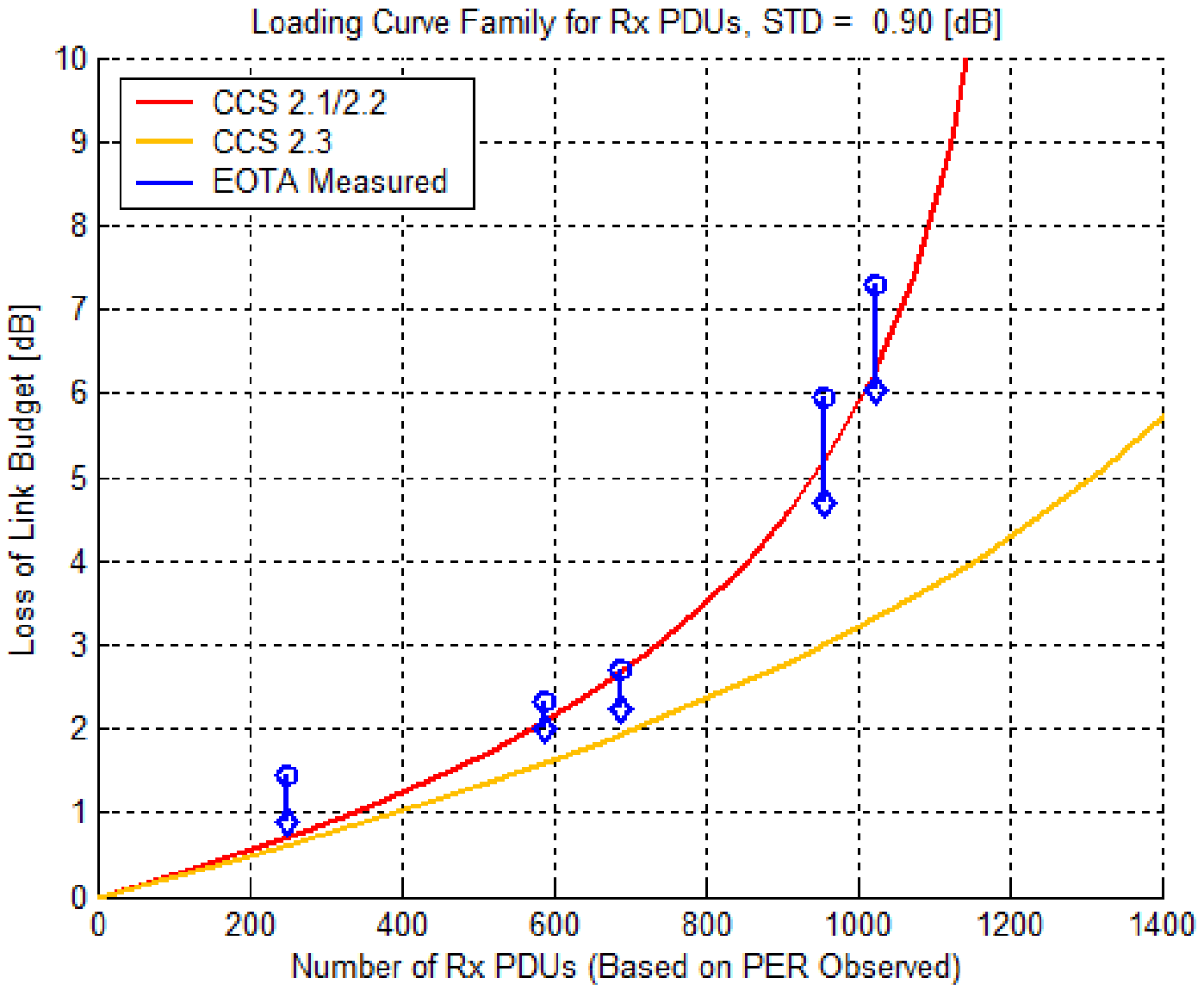


Physical Layer – RPMA Overview

- RPMA is a key component to support 1200 of PDUs per frame on the Uplink (recall DL is TDMA)

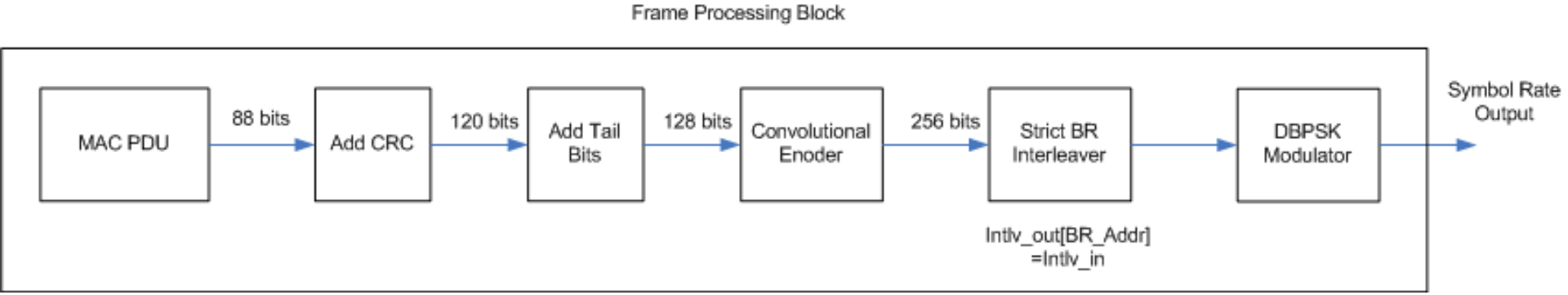
- Random Phase Multiple Access
  - Requires no coordination with other UL users.
  - As long as no two packets arrive with the same PN sequence offset (PN “Phase”), the AP can resolve a large number of simultaneously received PDUs.
  - Two arriving packets at the same chip timing is considered a collision. Collisions are “random”, but the RPMA space is vast.

Physical Layer – RPMA Capacity

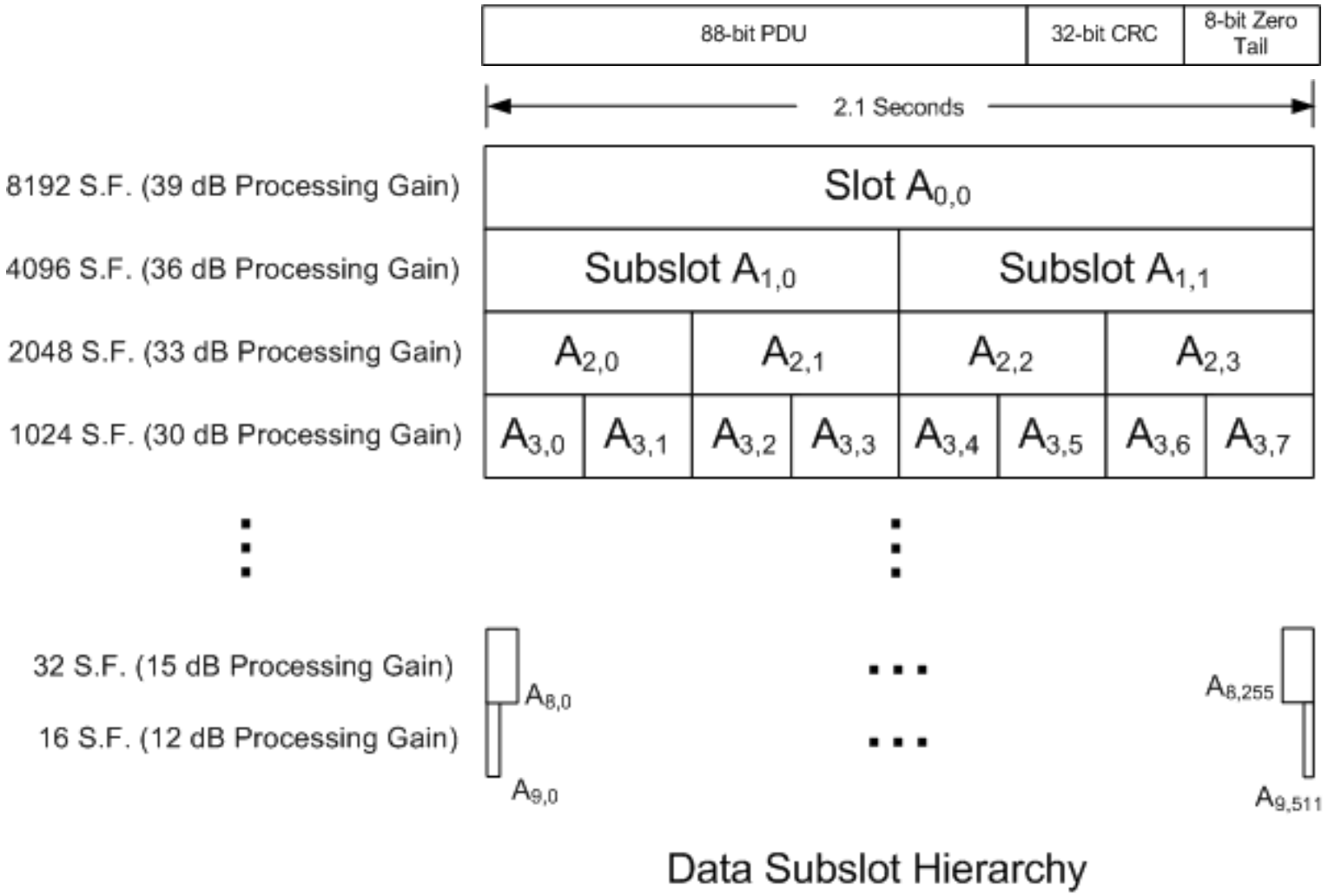


Physical Layer – Protocol Data Unit (PDU)

- A PDU is the fundamental data unit delivered by the MAC layer into the PHY from a L1 perspective.
- Comprises 64-bits of MAC data payload, and 24 bits of MAC header.



Physical Layer – PDU Hierarchy



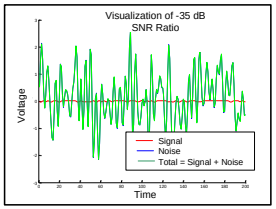
PDU Duration is a function of SF

Ingenu RPMA Network

Game Changing Wireless Revolution

Coverage

10,000 X Better Receiver Sensitivity

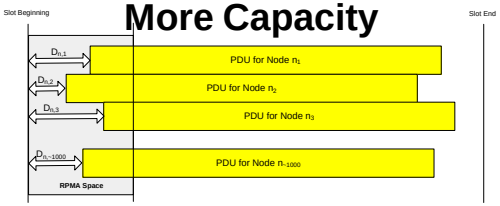


Lowest Total Cost Of Ownership

Technology	Cost per Sq Mile
ORW	$244
SSN	$1,040
Itron	$2,780
Sensus	$12,195
PLC	$795

Capacity

Order of Magnitude More Capacity



Unprecedented Data Richness

Technology	Price per Mbyte (of offered capacity)
ORW	$0.03
SSN	$1.32
Itron	$0.38
Sensus	$1.27
PLC	$25.37

Reliability

Star Topology Robustness

Thermal noise floor
-108.5 dBm

There When You Need It

***FACT**: Competitor's mesh took 72 hours to come back online after a significant power outage*

***FACT:** Ingenu RPMA network never went down*

Medium Access Control 2.1

MAC Layer – Key Features

- Reliable Data Delivery Services
- Secure
- High Capacity
- Scalable
  - Multiple gateways for High Availability, Redundancy and Load Balancing
- Over the Air Upgrades for End-points.
  - No significant capacity degradation.
  - No service outage
- Multi-casting Capable
- Low Power Optimized

MAC Layer – Reliable Delivery

- Uplink
  - Reed Solomon encoding designed to operate with up to 60% channel induced PDU error rate.
  - Additional parity symbols are “dribbled” out until success or timeout.
- Downlink Unicast
  - Unicast DL rely on a simple Automatic Repeat Request (ARQ) scheme
  - Retry until success or timeout.
- Downlink Broadcast
  - Endpoint firmware upgrade, network configuration changes, host firmware upgrade.
  - Very robust Reed Solomon encoding
  - Payload “Image” repeated during a N-day broadcast interval.
  - “Best effort” in the sense that when the broadcast interval ends, there is no subsequent re-attempts.
  - Positive ACK to aid with mitigation process.

MAC Layer – Reliable Delivery (cont'd)

- Downlink Multicast—Multi User Downlink (MUD)
  - Multi-cast groups are best thought of as statically configured at deployment time. Neighborhood, county, street, venue (i.e. park, concert hall, etc…)
  - Messages are authenticated with a MUD group security key; consequently, message latency is ~12 minutes. Future release expected to eliminate authentication requirement
  - Multicast DL is "Best Effort" at MAC layer. Application will be responsible for reliable delivery aspects.
  - Future Release: Ingenu's uStream protocol can serve as this application layer to manage reliable delivery of MUD (among other things).

MAC Layer – Communications Model

- Ingenu's RPMA System is not a "polling system"
  - Polling end-points is not a strong suit due to limited DL capacity.
  - Capacity is optimized when in the UL direction.

- End-points nominally follow a communications transmit schedule referred to as an "Update Interval" (UI).
  - Programmable reporting of 4.8 min, 7.2 min, 9.6 min,…. 12 hrs, 24 hrs.
    - Usually used for status reporting and data gathering.
  - Asynchronous reporting. Host has ability to "wake the end-point" to send an asynchronous report at any time.
    - Usually reserved for "exception" or "alarm" cases.

MAC Layer – Communications Model (cont'd)

- Transmit schedule is uniformly distributed in time amongst population of end-points.
  - Autonomous and non-negotiable.
  - Promotes system capacity.

- End-points nominally follow a communications receive schedule referred to as a "Listen Interval" or LI
  - LI = 0. Listen every frame (e.g. pageable). Only used for non-low power applications requiring low latency.

  - LI = nonzero. Node listens at the same schedule as the UI. Otherwise, the node is in a deep sleep state. This allows for low power consumption.

MAC Layer – Communications Model (cont'd)

- Unicast DL Messaging and Paging
  - Normally DL Unicast to a end-point can only occur on the scheduled UI.
  - Latency is dominated by where in the LI interval the command is generated.
  - Paging allows for low latency Unicast DL Messaging.
  - Maximum of 5 end-points can be paged per 4.64 sec frame.

MAC Layer – Data Rates

- Individual end-point link data rates are low
  - Purpose-built for the DA and AMI application space
  - 64-bits of application payload per MAC PDU.
  - Depending on link conditions, anywhere from 1 to 512 PDUs can be transmitted per 4.64 second frame.

System Version	SF	bytes/day	Kbytes/day	kbytes/day (w/margin)	bits/second
1.4	512 SF	237585.6	232	139.2	22.0
1.4	8K SF	73713.62	72	43.2	6.8
2.x	512 SF	471480	460	276.3	43.7
2.x	8K SF	92418.9	90	54.2	8.6

Note: Assumed 30% UL/DL PER

- Better described as practical aggregate data rates.
  - UL throughput of up to 100 MB/day
  - DL throughput of
    - Up to 72 Mbytes/day of unicast user data
    - Up to 144 kBytes/day of multicast user data
    - Up to 72 kBytes/day of broadcast user data

Downlink is a “precious resource” that should be used sparingly!

MAC Layer – Latencies

- Latencies are dependent on the following:
  - Channel conditions (PERs and link budget)
  - System Loading
  - SDU size
  - AP parameter settings (UL PDU transactions allowed per frame)

- Typical Values (typical DL commands 1 to 2 PDU sized SDUs)
  - DL Unicast (1 end-point): ~ 30 seconds
  - DL Unicast (N end-points): ~ 1.25*N + 30 seconds
    - Typically collapses to ~20-30 seconds for nodes up to ~10
    - Doesn’t really scale to 1.25n+30 until you get up to 100’s of nodes simultaneously addressed
  - DL Multicast (MUD group statically assigned): ~12 minutes

MAC Layer – Service Data Unit (SDU)

- SDU is the fundamental unit of application data transfer
  - Reliable means that the SDU is positively “acknowledged” upon success
  - Minimum size is 3 PDUs (8 bytes of user payload + 16 bytes of security overhead)
  - Maximum size is 60 PDUs (464 bytes of user payload + 16 bytes of security overhead)
  - Payloads bigger than a single SDU (464 bytes) must be further segmented and reassembled at the application layer (e.g. Ingenu’s uStream protocol).

MAC Layer – System Selection

- End-points maintain list of APs belonging to network
  - Typical list sizes range from 8 to 16.
  - Proper re-use code planning helps in keeping this list small
- Variables affecting AP selection
  - Likelihood of closing the link (best link budget)
  - AP Loading
  - AP Interference
- Once the best candidate AP is selected, a Join Process begins.
- Exponential back-off timers prevent undue “chatter”, conserves power.
  - Backoff timing parameters are application specific.

MAC Layer – Join Process

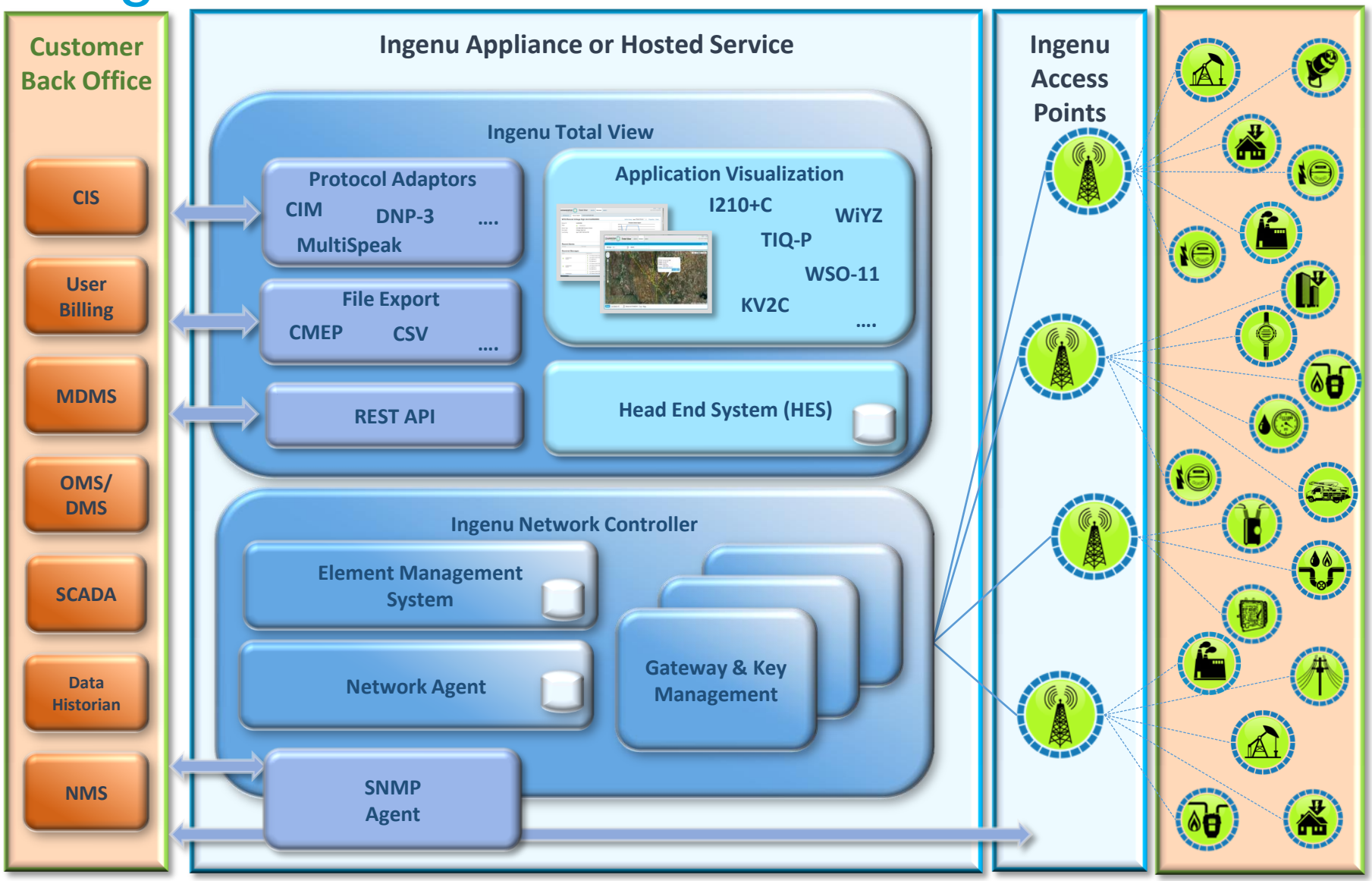
- BCH0 demoded to get relevant network wide parameters
- End-point transmits JOIN-REQ message
  - Included in JOIN-REQ are the authentication credentials to target AP.
  - End-point scans DCH and awaits confirmation.
- AP responds with JOIN-CNF message
  - AP receives JOIN-REQ, forwards to GW, which then contacts the Key Management Server (KMS) for End-point Authentication.
  - Upon authentication, a DL unicast JOIN-CONF message is sent back to the End-point.

MAC Layer – Security Concepts

- Mutual Authentication – End-point devices will only join a valid network and only valid end-point devices will join a network.
- Message Authentication – AES-128 CMAC. Immune to replay attacks.
- Message Confidentiality – Encryption using a 3-key 3DES (192 bit key) at communications layer and AES-128 at modem layer.
- Limited Anonymity – Communications link does not disclose the identity of the meter
- Secure Firmware Upgrade – No “over the air” key exchange.

Network Operations

Ingenu Solution Architecture



Network Operations

- RPMA Network spans two functional domains
  - RF Domain
  - IP Domain

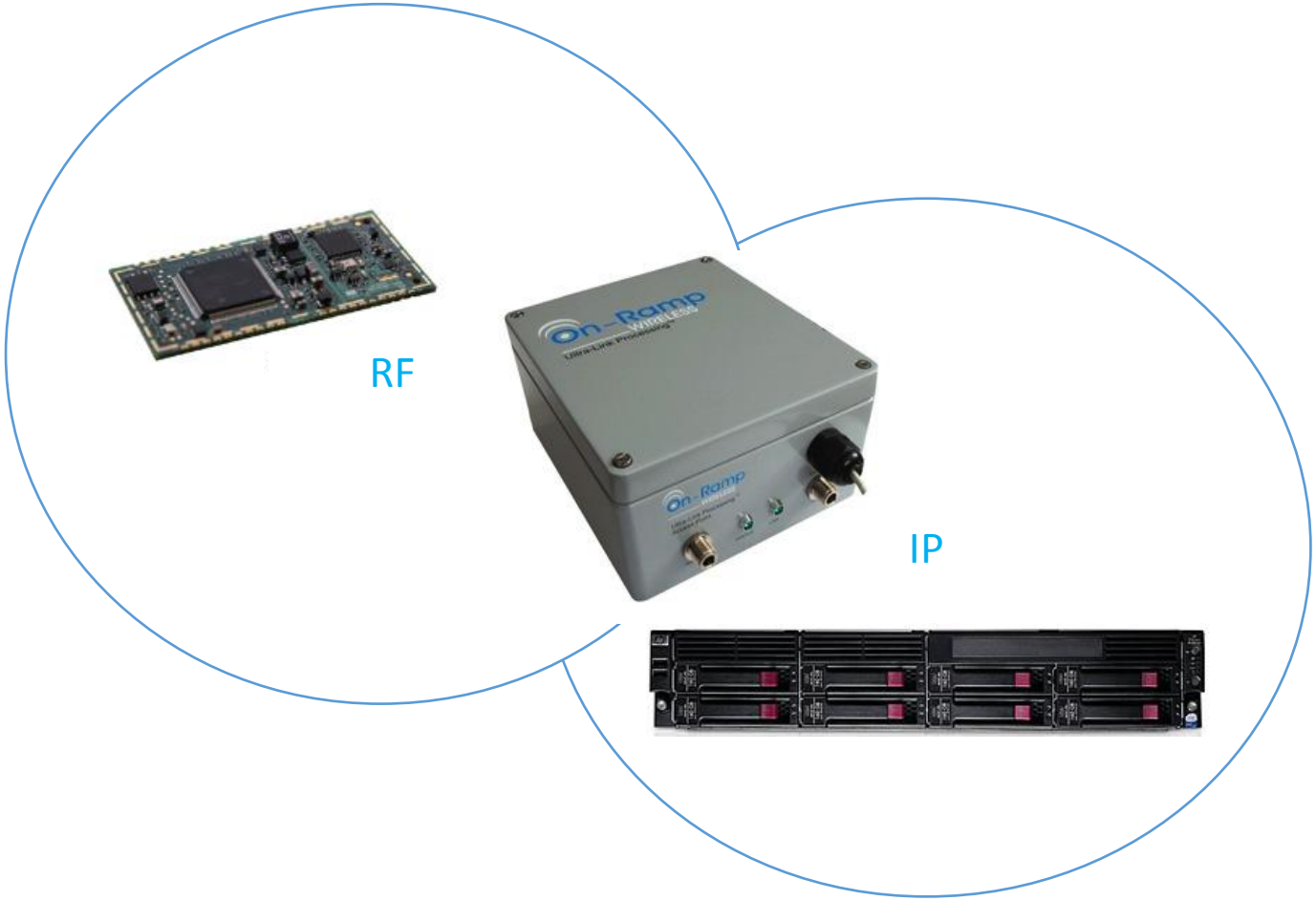
- RF Domain
  - Network planning
  - Network Deployments

- IP Domain
  - Backhaul
  - Security
  - Monitoring

Network Operations

- Backhaul
  - Connecting APs to the “head end” system.
  - “Standard” IP technologies uses
    - TCP
    - SSL
    - DNS
    - NTP
- Security
  - Node Security ties in via key management process.
  - Backhaul and head-end security
    - Nothing novel here – standard IP best practices.
- Monitoring
  - Mostly off-the-shelf “standard” technologies (nagios, cacti)
  - Some homegrown and OTV specific approaches

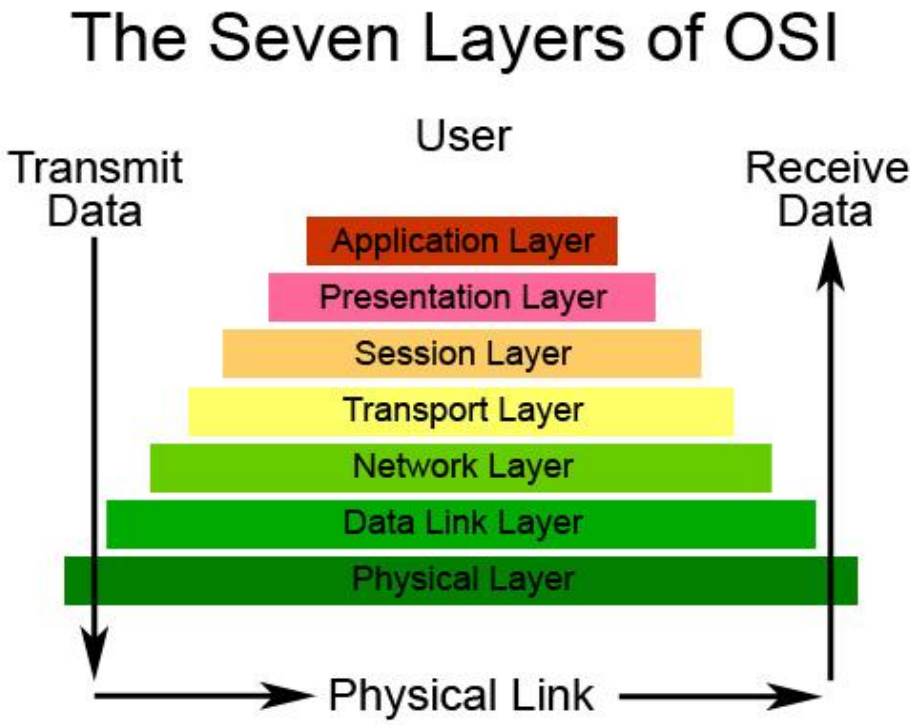
AP Is In Both Domains

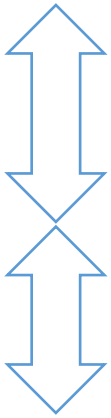


Separate Domains

- Different expertise.
- Different tools.
- Different failure modes
  - IP down – immediate large, catastrophic failure.
  - Periodic RF interferer – might take months to determine.
- The RPMA Network is NOT an IP network.
  - No IP connectivity to the end-point.
- The RPMA Network requires an IP Network.

Two Layers (OSI analogy)





Application Layer

Communications Layer

Two Layers (Support Stack)

- Communication System
  - IP Connectivity from APs to GW service.
  - Management of APs and GW service
- Application Layer
  - Host code on the end device
  - OTV XML Service APIs running on the Appliance.
- Differentiating each is important to troubleshooting.
  - “Network doesn’t work” vs. “device x doesn’t work.”

Communication Layer

- Data is transmitted and gathered at AP over RF, and then securely transmitted to gateway service over TCP.

- The specifics of the TCP connection will be dependent on the backhaul options available at the site.
  - Cellular Modems – Useful for some remote (but not too remote) installs that have no pre-existing connectivity.
  - Microwave, Satellite or other systems – Anything goes.
    - Bandwidth > 512k bps (peak data rate, nominal data rate is lower)
    - Data usage, 5 GB / Month “ Data Plan” or better.
    - One-way latency is less than 500 ms (on average.)

Breakdown by Element

Element	RF	IP	Comms	Apps
End-point	X(node)		X(node)	X(host)
AP	X	X		
Appliance		X	X(gateway)	X(OTV)

Backhaul

- Connection between AP and Gateway is “the backhaul.”
- “Connected” : This means an AP has a valid TCP/SSL connection to the GW.
  - This requires a few IP dependent services. (ntp, dns)
- “On-line” : This means the AP is able to begin TX/RX.
  - This requires a GPS fix.
- A connected AP does not guarantee “On-line” status.
  - Can’t get a GPS fix.
  - Taken offline by an operator to change RF configuration parameters.
- An “On-line” AP may not be connected.
  - The backhaul recently went down. The AP will attempt to buffer for up to an hour.

Backhaul – Dependent Services

- NTP
  - NTP is required because AP needs valid time PRIOR to GPS fix.
  - If NTP is not reachable, SSL session establishment will fail and AP will not connect to gateway.
- DNS
  - Connecting to the GW services via public DNS name is the preferred approach.
  - Due to some limitations of the embedded linux version deployed on the AP, a reachable DNS server is required even if you are specifying all IP address for dependent services.
- Repeat: Despite having GPS, the AP still needs a notion of local time and will not connect to GW if it doesn’t a reasonably valid time.

Backhaul – Security

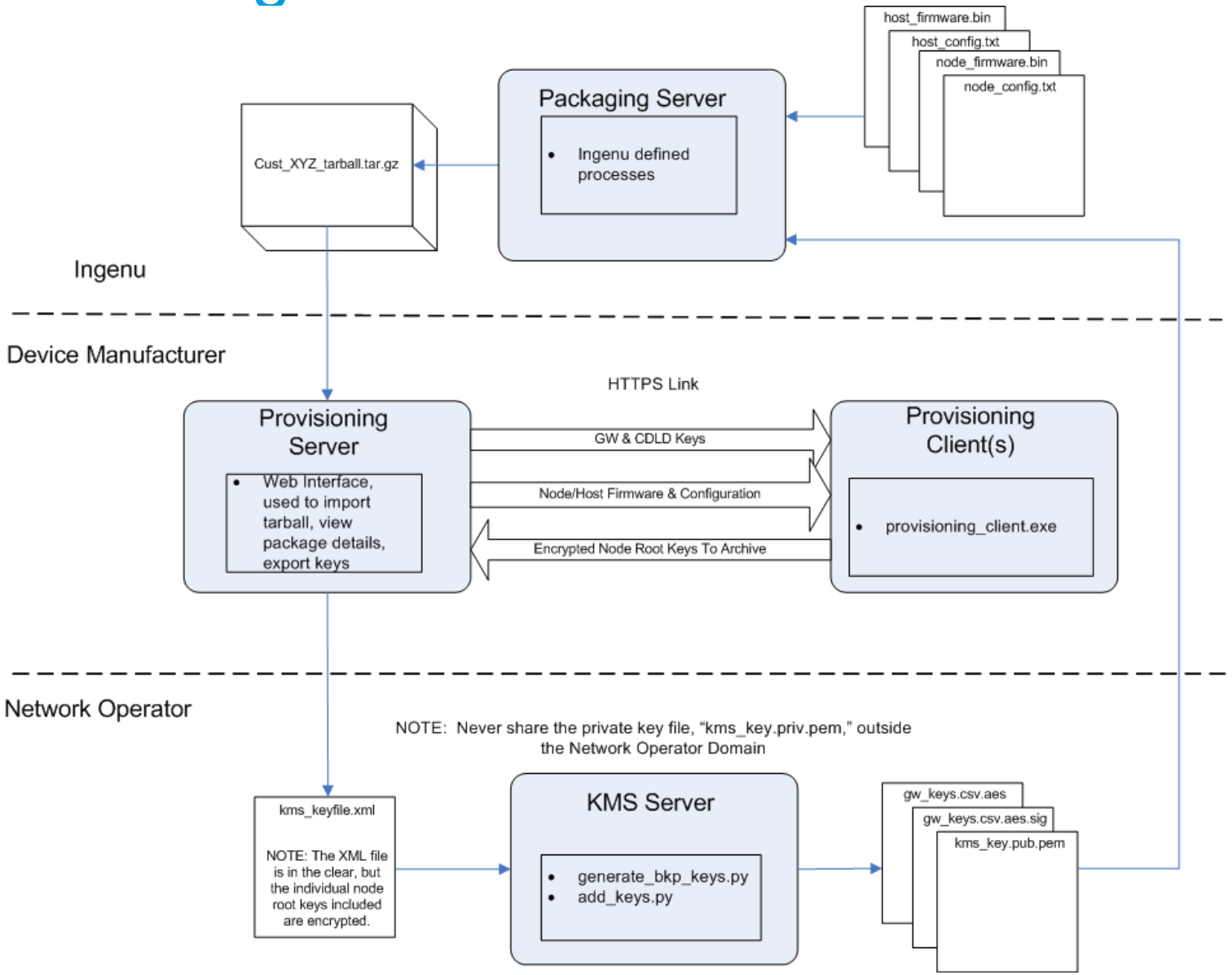
- The full suite of SSL options exists for AP-GW communication.
  - Default is a self-signed cert that is shared across all APs.
  - Per AP certs are possible.
  - CA is possible.

- For hosted services, Ingenu locks access from a known IP or IP range.
  - For a customer-appliance, this is also suggested for additional security.

Key Management

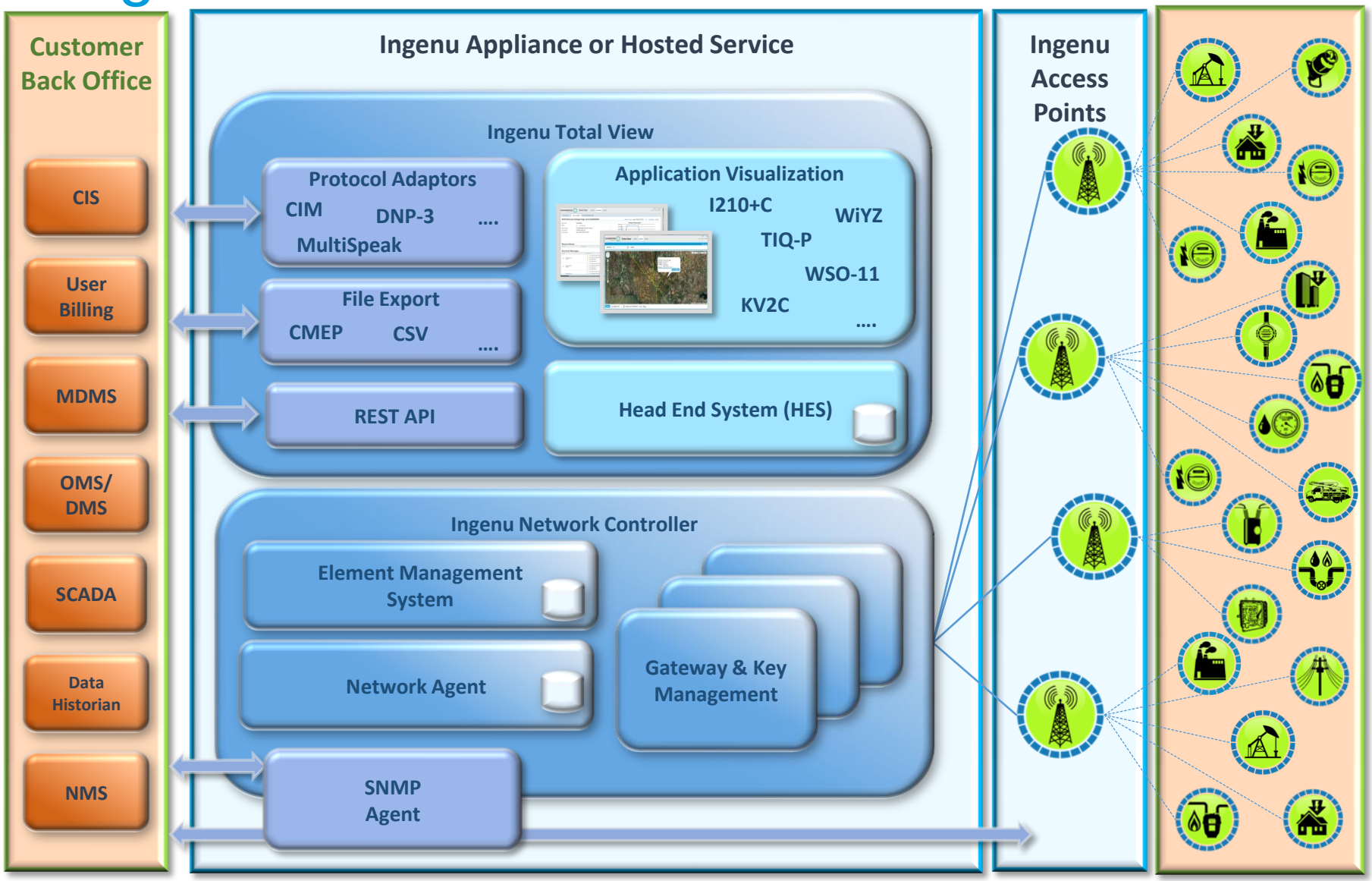
- RPMA networks use a symmetric key system for securing node communication.
- Keys are provisioned at the end-device at manufacturing time.
- Keys need to be added into the key management service on the appliance prior to adding nodes to the gateways Access Control List (ACL)
- Two levels
  - Add keys, on-box on the appliance (e.g. import into KMS)
  - Add devices into the ACL of the GW, through the EMS.

Provisioning 3.x Architecture



RPMA Solution Architecture

Ingenu Solution Architecture



Enabling a Growing Ecosystem

Ingenu Meter Communications Modules

- ANSI and IEC integration-ready MCMs
- Software configurable for meter capabilities, operator requirements

Ingenu Reference Platform

- Fully functional sensor communication module
- Integrated microNode
- Integrated K20 Processor
- Kit includes hardware design and manufacturing plans, reference software, and development guidelines
- Endpoint certification process

RPMA

MACHINE NETWORK

dNode

- microNode with pre-integrated antenna diversity
- 20-Pin connector for easy PCA integration

microNode

- Lower cost and improved power consumption
- Antenna diversity support
- Global availability
- ULP 90nM SoC

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Connected by Ingenu RPMA

Item	Item Description
Ingenu Development System	Development System VM including the following : • Gateway Controller & Security Services • Element Management System • Network Agent • Total View Application • Interface Support • Related documentation and development license
Ingenu Access Point	• Standard FCC/IC or ETSI Access Point • AP Installation & Commissioning Guide
AP Lab Mounting Kit	• Indoor mounting kit w/ POE • Indoor GPS antenna

Reference Platform	Platform Kit includes:
	• Hardware design collateral (schematics, gerbers, etc.)
	• Software source code (host API code, host reference application)
	• Development documentation:
	  • rACM Quick Start Guide and Developer Guide
	  • Interface Guides
	  • microNode and dNode Integration Specifications

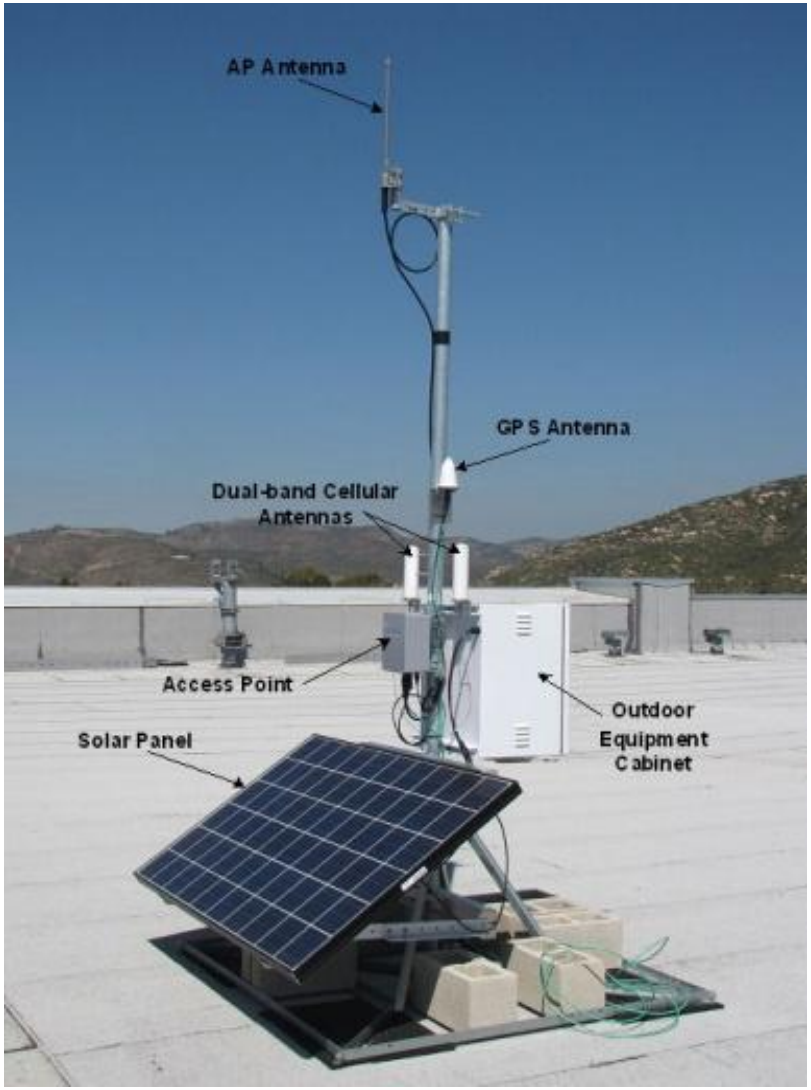
Development Licenses	Development licenses for Development System VM and Reference Platform
Engineering Support	Support packages available per developer requirements

Ingenu RPMA Access Point

Ingenu Access Point

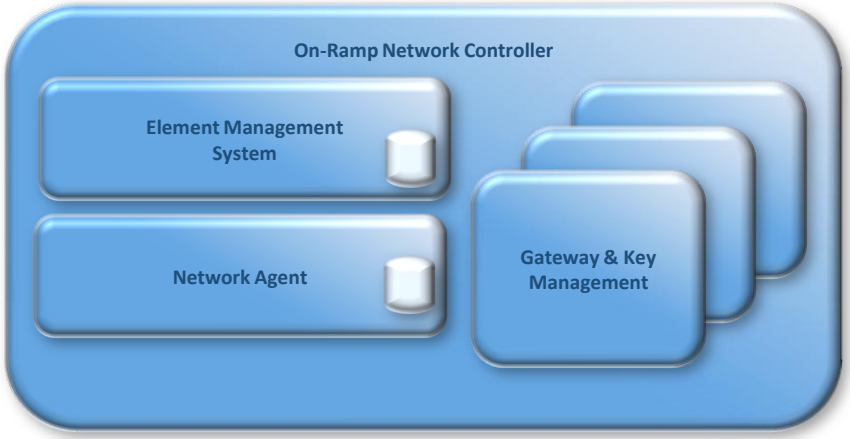
- Provides wide area wireless coverage to sensors with Ingenu Nodes
- Transports data from field to back office on secure IP backhaul (e.g. cellular, DSL, fiber,…)
- Each AP can support up to 16K endpoints
- Rapid and low cost deployment (50-300 sq. miles of coverage a day)
- Supports various indoor and outdoor mounting options and powered or un-powered installations
- EMC certified by FCC, IC, ETSI, and numerous regional entities
- Environmentally certified for utility and industrial applications

Access Point with Deployment Options =Base station



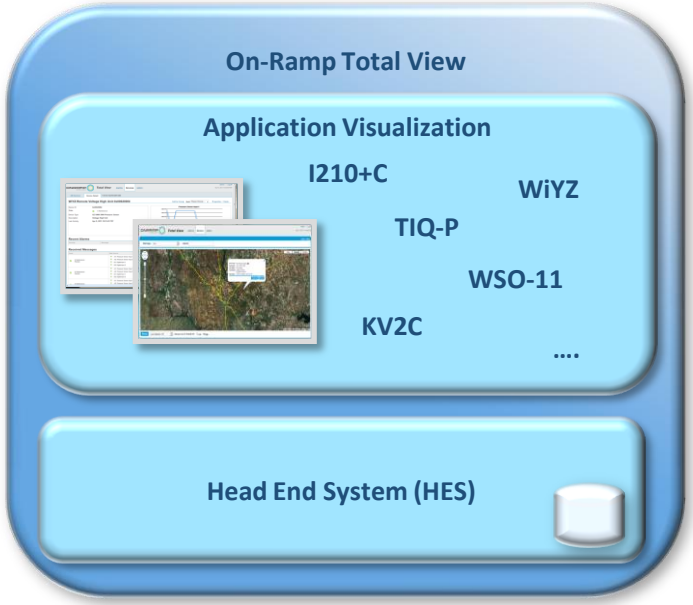
Ingenu Network Control & Management

- The high capacity, high availability **Gateway (GW)** manages network security and AP connections with back office management applications.
- The **Element Management System (EMS)** manages network elements with intuitive interfaces for monitoring network performance, managing device configuration and firmware updates.
- The **Network Agent** provides network diagnostic and database services



Ingenu Wireless Device Management

- The **Ingenu Total View** web application provides:
  - An intuitive interface for visualization of sensor performance, alarms, active commands, etc.; supported devices include meters, distribution automation devices, and remote I/O devices.
  - Head End Services which parses/manages sensor data and manages sensor interaction commands (e.g., device triggers, system alarms).
  - Database services responsible for managing storage of the end point application data



Ingenu Supported Interfaces

❖Sensor Information:

Protocol Adaptors

- Support specific protocol data interaction with SCADA, MDMS, etc., systems
- Connected by Ingenu ecosystem partners have added protocol support

File Export

- Export CMEP files for use in billing, meter management, or analytics applications
- Locally save an export in CSV format

REST API

- Access uplink raw or parsed device data
- Send commands or configuration updates to one or more devices

❖Network Information:

SNMP Agent

- Access network health information
- Diagnose network issues

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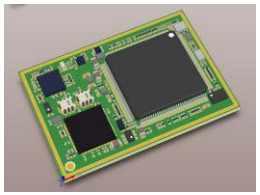
End-points and Applications

Modular Components

- dNode
  - Drop in replacement for eNode (1st generation silicon “eNode” is EOL).
  - Based on uNode chipset.
- uNode
  - Current (2nd) generation silicon
  - RPMA wireless module designed to lower cost and improve power performance
  - Antenna Diversity support
  - FCC Part 15C, IC RSS 210 Issue 7, and ETSI certified
- uNode2 (Available Q4 2015)
  - Various hardware updates to uNode module
  - Optimized antenna tuning & higher output PA.
  - Continues to use 2nd generation silicon.
- nanoNode (Available Q1 2016)
  - Form factor (size & packaging) module optimization.
  - Continues to use 2nd generation silicon.



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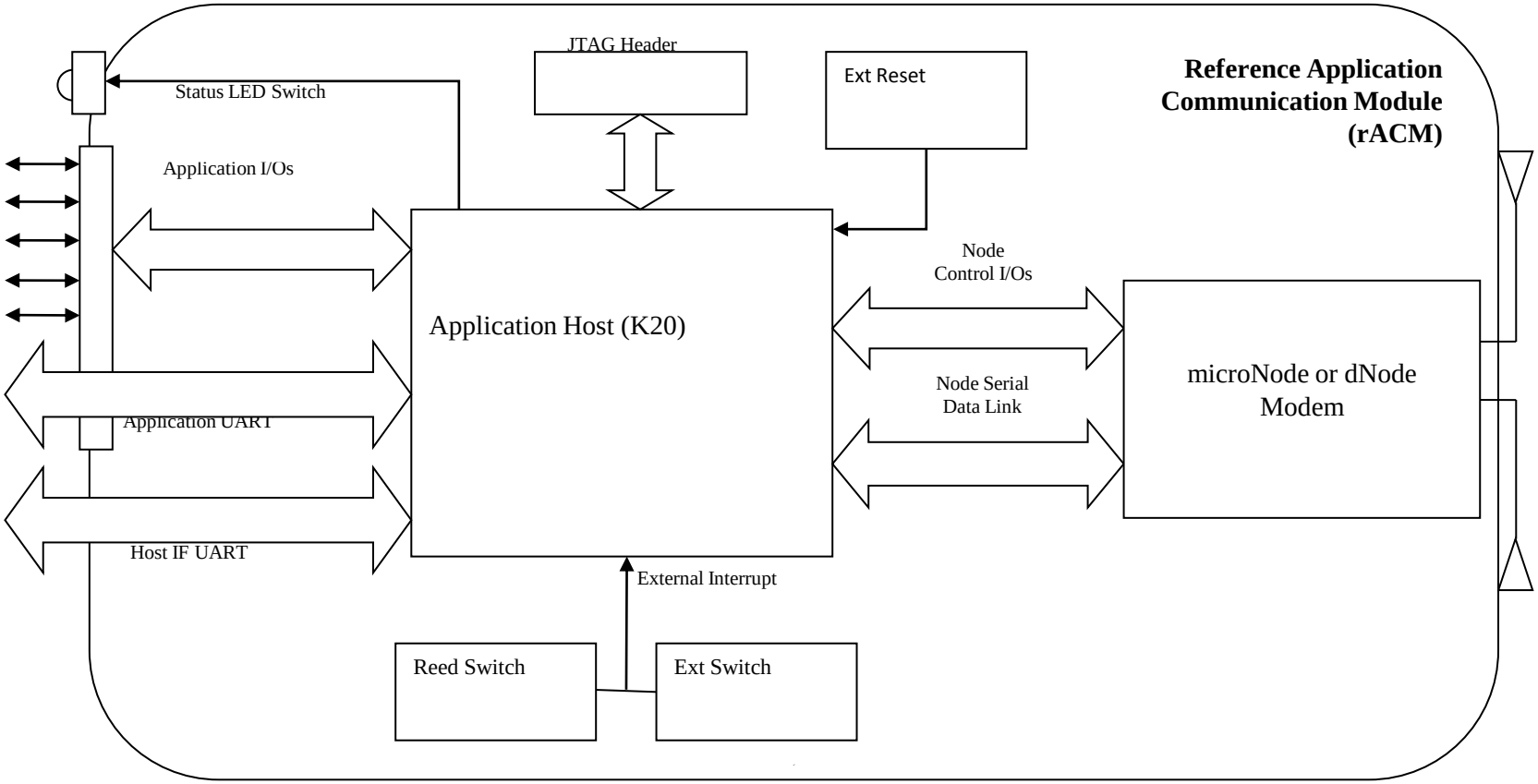
Reference Platform

- rACM (reference Application Communication Module)
  - Ingenu Reference Platform is a working sensor – ready to jump start new development.



End-Point Development

- rACM Development Kit
  - 010-0024-00_A_Host_Common_SW_Integration_AppNote.pdf
  - 010-0038-00_A_OTV_REST_API_Guide.pdf
  - 010-0074-00_B_Provisioning_Guide.pdf
  - 010-0105-00_A_rACM_Developer_Guide.docx
  - 014-0033-00_E_microNode_Integration_Specification.pdf
  - 409-0038-01 REV-01 rACM Schematic.PDF
  - 410-0038-01 REV-00 fab dwg.pdf
  - 430-0038-01 Gerber Files PCB.zip
  - 430-0038-01_PCB - Paste Gerber File Set.zip
  - 506-0038-01_PCB Pick and Place.csv
  - 509-0038-01 REV-00 Assembly Dwg and Rework.zip
  - 510-0038-02_agile_20130820_110242490_BOM.xls

Application Visualization and Integration

- Ingenu Total View REST Interface
  - URL-XML interface to pull data from the sensors or push updates and queries to the device.
  - Requires documentation of the requirements, design/implementation of the integration, and validation of the 2-way, end-to-end information flow.
  - New sensors or RTU devices may require Ingenu development activity.