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Smart Grid Fundamentals

Other Networking Technologies

António Grilo

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LPWAN Technologies: LoRaWAN

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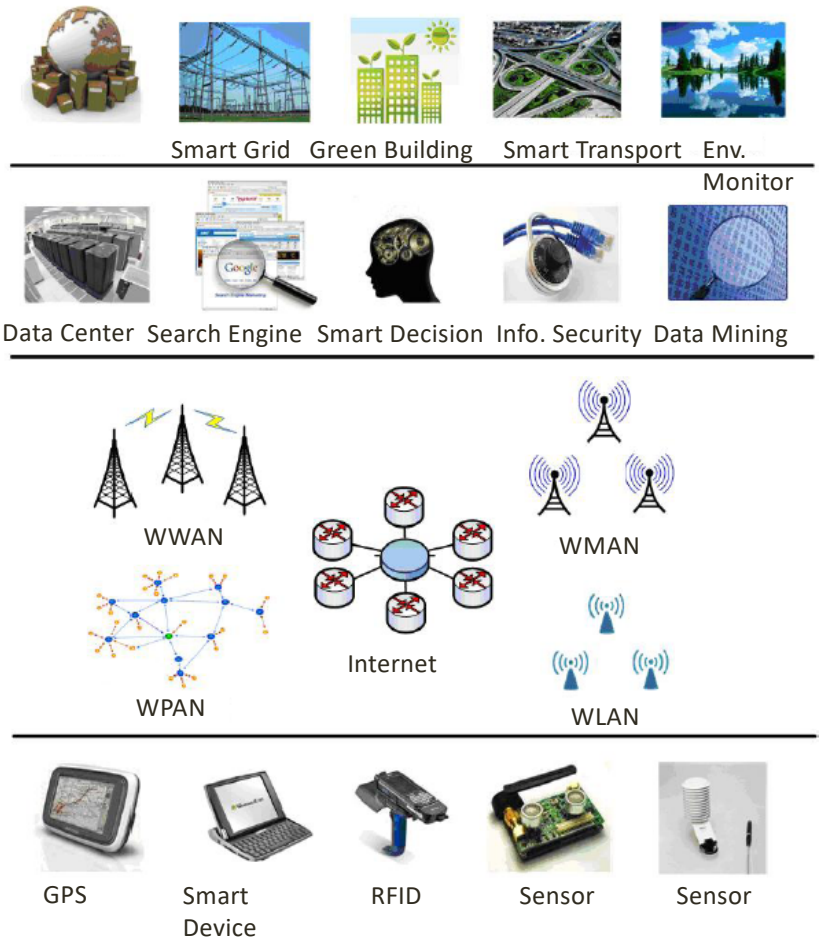
IoT

LoRaWAN

PLC Prime



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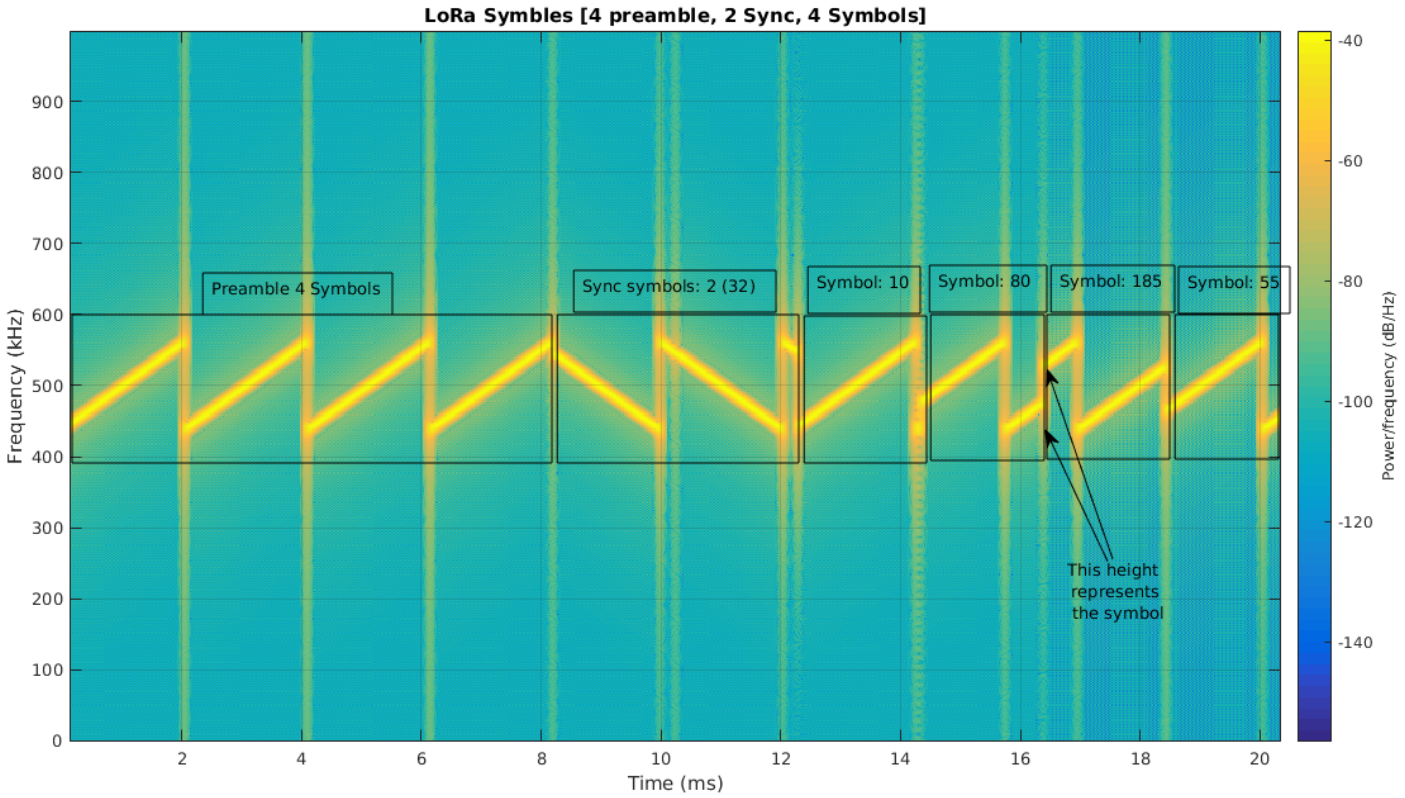
Low Power Wide Area Network (LPWAN)

- LPWAN main critical factors:
  - Network architecture
  - Communication range
  - Battery lifetime or low power
  - Robustness to interference
  - Network capacity (maximum number of nodes in a network)
  - Network security
  - One-way vs two-way communication
  - Variety of applications served
- Examples: LoRaWAN, SigFox, NB-IoT, Weightless

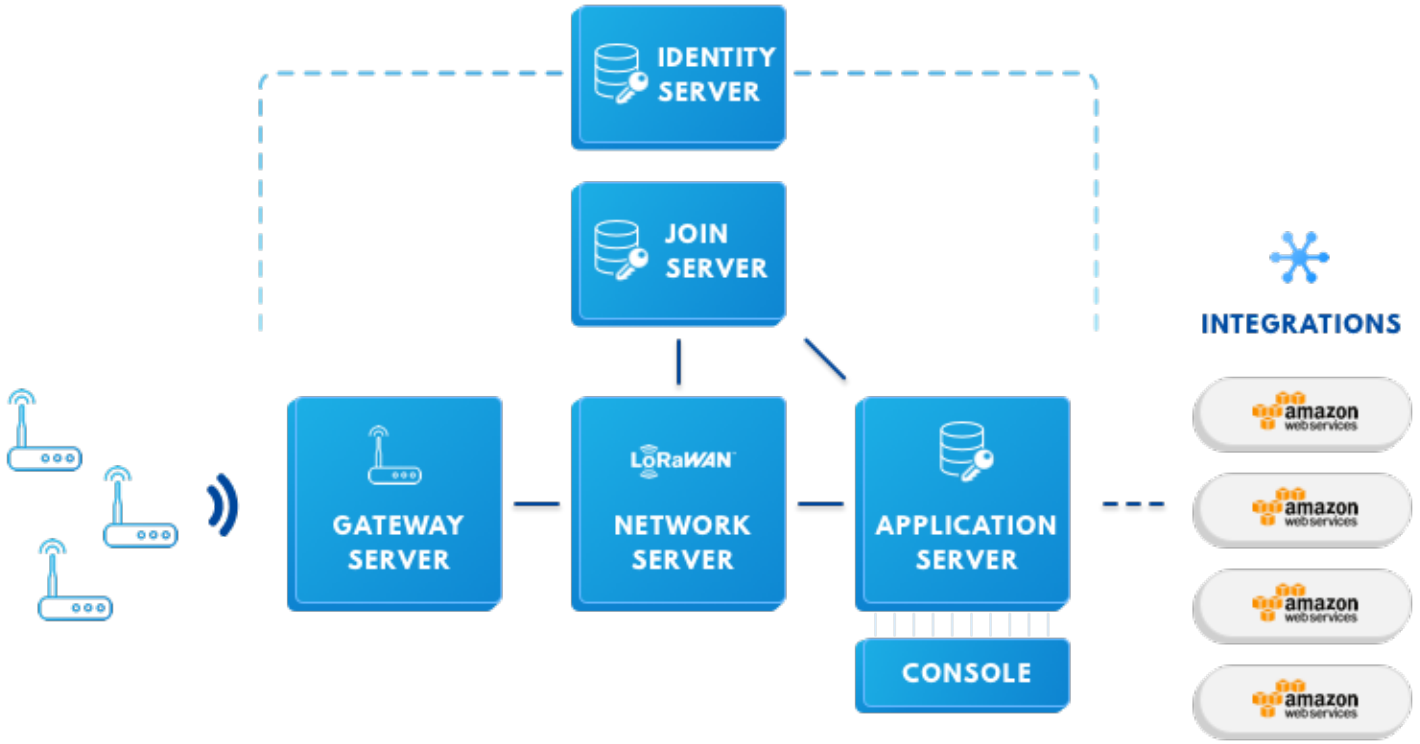
Long Range WAN (LoRaWAN)

- LoRa modulation:
  - Chirp Spread Spectrum



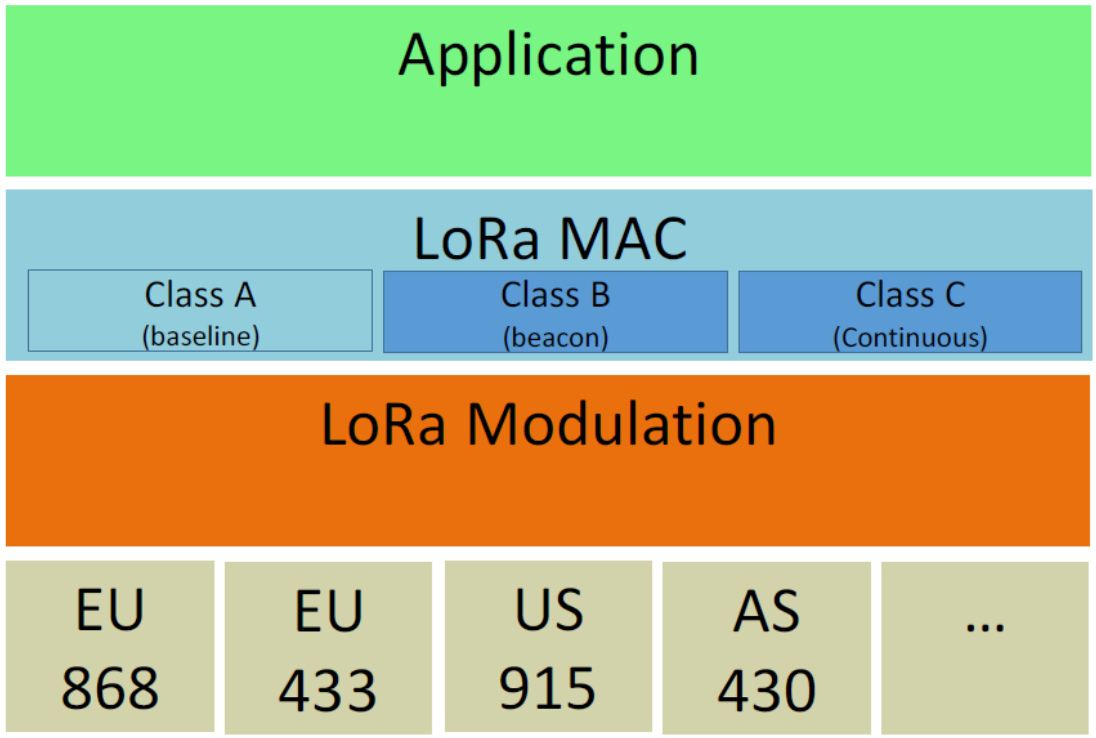
Long Range WAN (LoRaWAN)

- LoRaWAN Architecture:



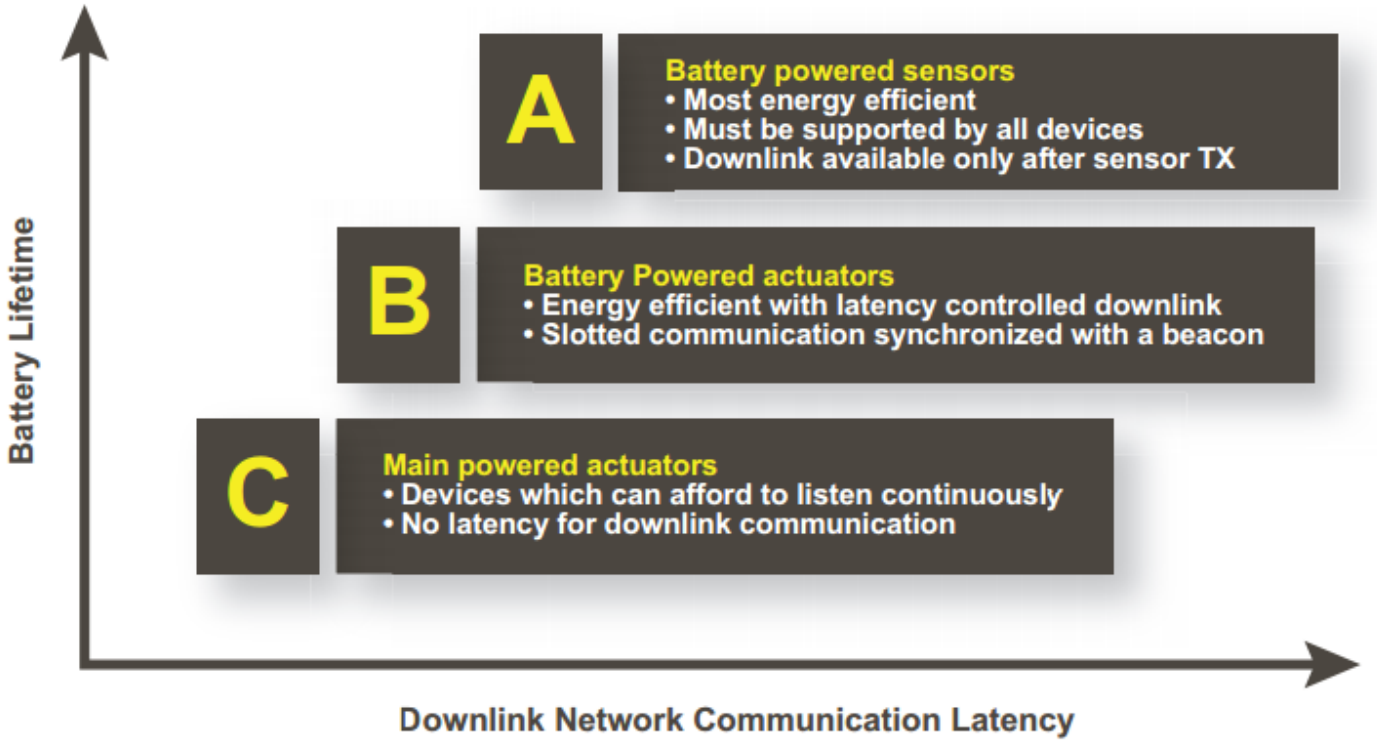
Long Range WAN (LoRaWAN)

- LoRaWAN Protocol Stack:



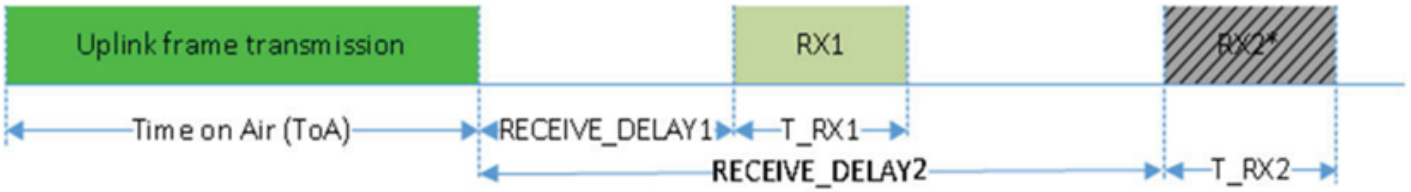
Long Range WAN (LoRaWAN)

- LoRaWAN Classes of End Devices (EDs):



Long Range WAN (LoRaWAN)

- LoRaWAN Transmission for Class A ED:
  - RX1 frequency and data rate are functions of uplink frequency and data rate.
  - RX2 uses fixed configurable frequency and data rate.



* RX2 does not need to be present if reply is received in RX1

Long Range WAN (LoRaWAN)

- LoRaWAN Performance:

Table I. LoRaWAN data rates settings and frames characteristics

Data rate (DR)	SF	Band width, kHz	Modu-lation	maximum MACPayload size, bytes	Maximum FRMPayload size[1], bytes	Shortest downlink frame ToA, s	Longest downlink frame ToA, s	Shortest uplink frame ToA, s	Longest uplink frame ToA, s
0	12	125	LoRa	59	51	0.991	2.793	1.155	2.793
1	11	125	LoRa	59	51	0.578	1.479	0.578	1.561
2	10	125	LoRa	59	51	0.289	0.698	0.289	0.698
3	9	125	LoRa	123	115	0.144	0.677	0.144	0.677
4	8	125	LoRa	250	242	0.072	0.697	0.082	0.707
5	7	125	LoRa	250	242	0.041	0.394	0.041	0.400
6	7	250	LoRa	250	242	0.021	0.197	0.021	0.200
7	n/a	150	GFSK	250	242	0.0032	0.0421	0.0035	0.0424

[1]- given that $FHDR_{OPTS}$=0

Table II. LoRaWAN ED performance for the different data rates

Data rate (DR)	No RX slots				ACK in RX1[1]				No ACK in RX2[2]			
	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %	Minimum packet period, s	PHY throughput, bit/s	APP throughput, bit/s	Max. duty cycle, %
0	2.7935	183.3	146.1	100	4.78	107.0	85.3	58.4	5.0	103.3	82.3	56.4
1	1.5606	328.1	261.4	100	3.14	163.2	130.0	49.7	3.7	137.5	109.5	41.9
2	0.6984	733.1	584.2	100	1.99	257.7	205.3	35.1	2.9	178.9	142.5	24.4
3	0.6769	1 512.9	1 359.2	100	1.82	562.3	505.1	37.2	2.8	360.5	323.9	23.8
4	0.7071	2 885.1	2 738.1	100	1.78	1 146.5	1 088.1	39.7	2.9	710.6	674.4	24.6
5	0.3996	5 104.9	4 844.7	100	1.44	1 415.8	1 343.7	27.7	2.6	795.8	755.2	15.6
6	0.1998	10 209.8	9 689.3	100	1.22	1 671.6	1 586.3	16.4	2.4	863.1	819.1	8.5
7	0.0424	48 113.2	45 660.4	100	1.05	1 951.0	1 851.6	4.1	2.0	998.2	947.3	2.1

[1]-assumed that the acknowledgement frame has no payload and is transmitted using the same DR (i.e., best-case scenario)
[2]-assumed that RX2 is open with DR0 settings (the default setting according to [3])

Long Range WAN (LoRaWAN)

- LoRaWAN Performance:

Table III. FICORA frequency regulations [15] and obligatory LoRaWAN channels in EU 863-873 MHz band

Frequency band, MHz	Duty cycle, %	Maximum power, mW ERP	LoRaWAN obligatory channels, MHz	LoRaWAN join request channels, MHz	Max 125 kHz LoRa channels[2]	Max 250 kHz LoRa channels[2]	Max 150 kHz GFSK channels[2]
863–868.6,868.7–869.2,869.4–869.65,869.7–870	0.1	25	-	864.1[1],864.3[1],864.5[1]	32	19	37
868.0–868.6	1	25	868.1[1],868.3[1],868.5[1]	868.1[1],868.3[1],868.5[1]	3	2	4
868.7–869.2	0.1	25	-	-	2	1	3
869.4–869.65	10	500	-	-	1	0	1
869.7–870.0	1	25	-	-	1	0	2
870.0–873.0	1	25	-	-	15	10	20
Total					47	29	57

[1]- LoRa modulation, 125 kHz bandwidth, DR0-DR5
[2]- the actual bandwidth of 200 kHz for 125 kHz LoRa channel and 300 kHz for 250 kHz LoRa channel (similar to [16]) and 150 kHz for GFSK channel are assumed.

LoRa	125	864.10 864.30 864.50 868.10 868.30 868.50	DR0 – DR5 / 0.3-5 kbps

Table IV. Maximum throughput per LoRaWAN channel and ED

Data rate (DR)	Bandwidth, kHz	Maximum APP throughput per channel, bit/s	Maximum APP throughput per ED per channel, bit/s		
			10% duty cycle	1% duty cycle	0.1% duty cycle
0	125	146.1	14.61	1.46	0.15
1	125	261.4	26.14	2.61	0.26
2	125	584.2	58.42	5.84	0.58
3	125	1 359.2	135.92	13.59	1.36
4	125	2 738.1	273.81	27.38	2.74
5	125	4 844.7	484.47	48.45	4.84
0-5 cumulative[1]	125	9 933.6	n/a	n/a	n/a
6	250	9 689.3	968.93	96.89	9.69
7	150	45 660.4	1 851.6[2]	456.6	45.66

[1]- given that the spreading factors for DR0-DR5 are orthogonal, the transmissions with different SF may coexist in the same channel at the same time
[2]- due to the need for opening RX windows after each frame, the maximum possible duty cycle is 4.1% (see Table II, acknowledged transmission)

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NB-PLC: PLC Prime

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PLC Standards and Typical Applications

LoRaWAN

PLC Prime

Table 9.3 PLC standards and typical applications

	Frequency band	Frequency range	Data rates	Standards[a]	Typical applications
LV-PLC	UNB	30 Hz–3 kHz	≤120 bps	TWACS	AMR, AMI NAN, direct load control
	NB (LDR)	3 kHz–500 kHz	Few kbps	HomePlug, IEC 14908–3, IEC 61334	AMI NAN, DA NAN
	NB (HDR)		≤500 kbps	HomePlug, IEEE 1901.2, PRIME, G3-PLC ITU-T G.hnem (G.9955/56)	AMI NAN, EV, FANs, HAN
	BB	1.8 MHz–250 MHz	Up to several hundred Mbps	HomePlug, IEEE 1901, ITU-T G.hn (G.9960/61)	Internet access (BPL), HAN, FANs
MV-PLC	Most of the LV-PLC-NB (LDR and HDR) standards support PLC over MV power lines. MV-PLC technologies are expected to mature in the next few years				FANs
HV-PLC	UNB	30 Hz–3 kHz	≤120 bps	IEC 60495, IEC 62488	Teleprotection
	NB	3 kHz–500 kHz	Few kbps to 500 kbps	IEC 62488	FANs

[a]Includes agreements within organizations of interested parties such as utilities and PLC product vendors

PLC Channel Impairments

- Attenuation with distance:
  - $P_d[dBm] - P_0[dBm] = -\alpha \cdot d[km]$
  - $\alpha \cong$ 40–80 dB/km
- Background noise / interference
- Impulsive noise

PLC NAN for AMI

LoRaWAN

PLC Prime

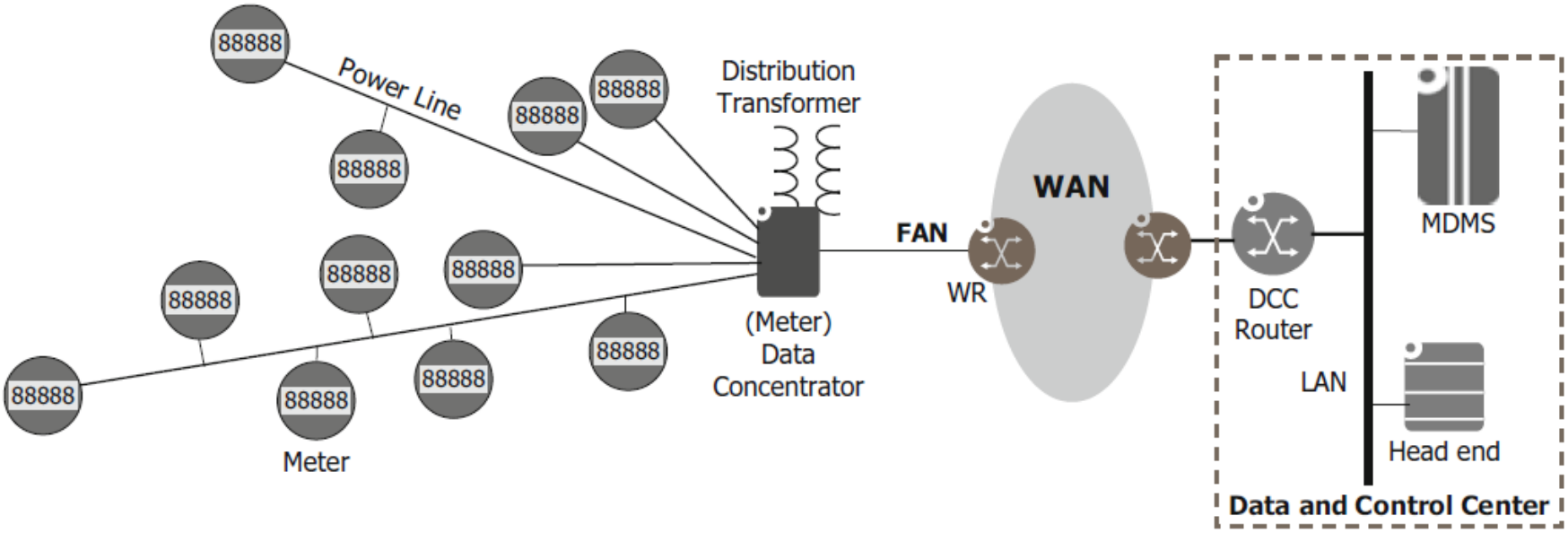
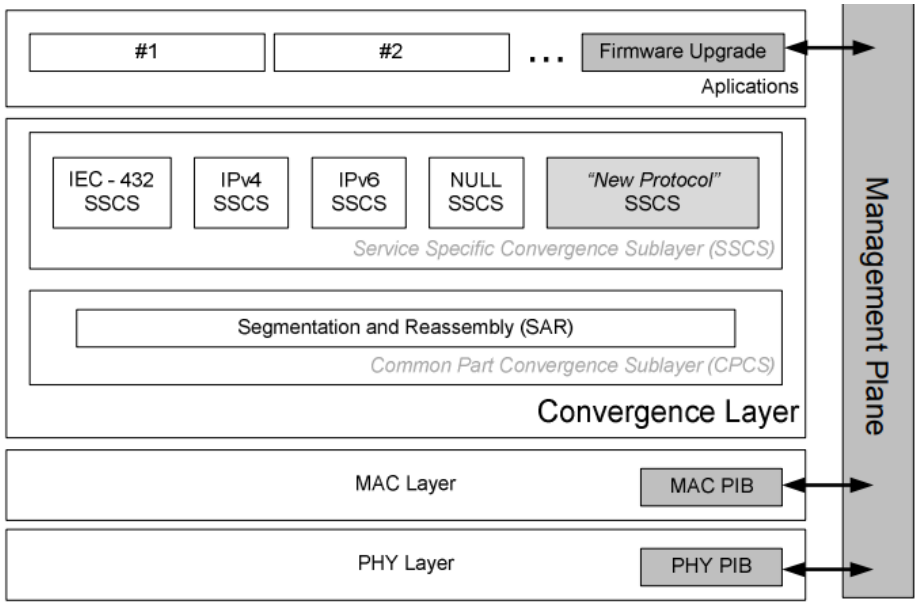


Fig. 9.5 PLC NAN for AMI

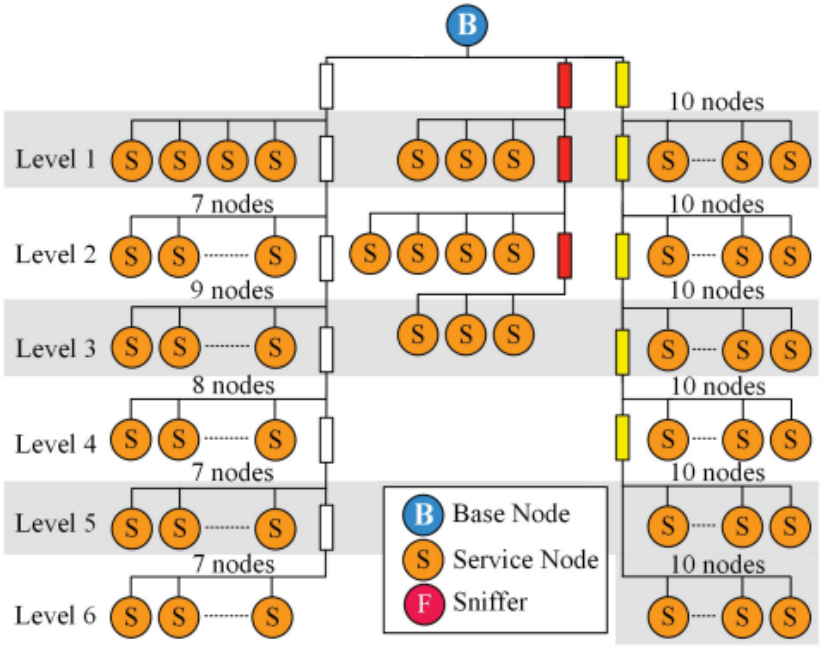
PLC PRIME

- PRIME = PoweRline Intelligent Metering Evolution.
- PRIME Alliance consortium manages PLC Prime development, evolution and certification.
- Defined in Recommendation ITU-T G.9904.
- Current version is PRIME 1.4.
- Uses Orthogonal Frequency Division Multiplexing (OFDM).
- Operates in the CENELEC A&B-Band and FCC band (41.992 kHz - 471.679 kHz).
- Modulations: DBPSK, DQPSK, D8PSK.
- Integrates Contention-free operation and CSMA/CA with priorities.
- Data rates as high as 40kbps-1Mbps.



PLC PRIME

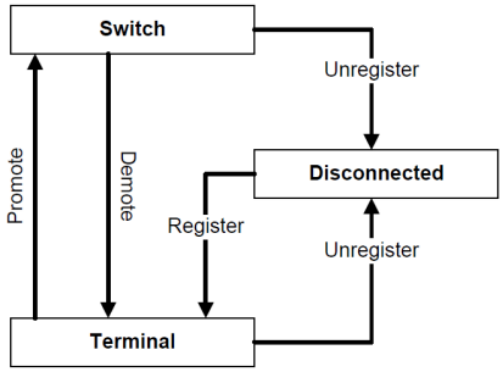
- PLC PRIME tree topology:
  - Base Node (BN) manages registration and CFP resource reservation
  - Service Nodes may operate as Terminals (leaf nodes) or be promoted to Switch Nodes
  - Switch Nodes relay traffic to/from other nodes
  - For multilevel CFP transmissions, BN allocates transmission time windows in all levels



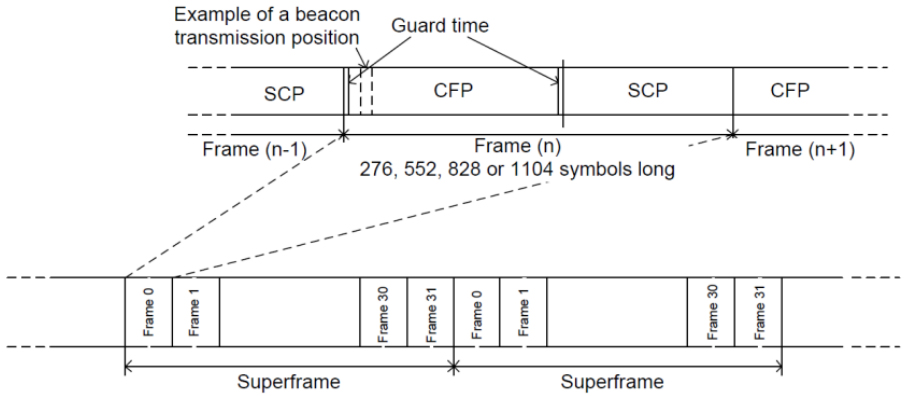
Based on Julio Corchado et al., "Application-layer Performance Analysis of PRIME in Smart Metering Networks", IEEE International Conference on Smart Grid Communications (SmartGridComm), 2016

PLC PRIME

- State machine of a PLC PRIME node:



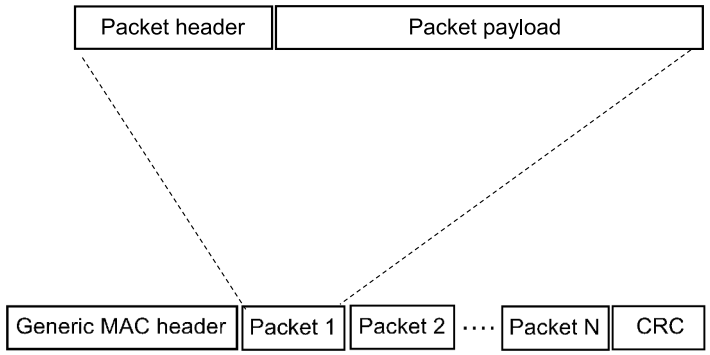
- Structure of a PLC PRIME frame:



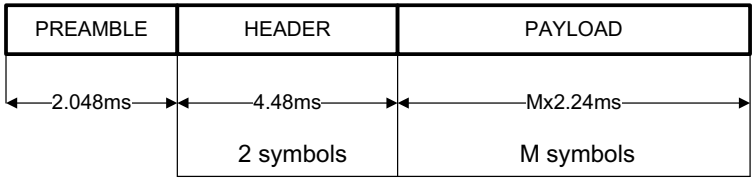
PLC PRIME

- Detailed frame structure (Generic PDU):

MAC



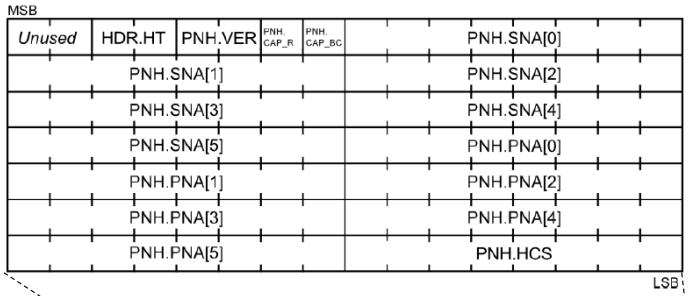
PHY



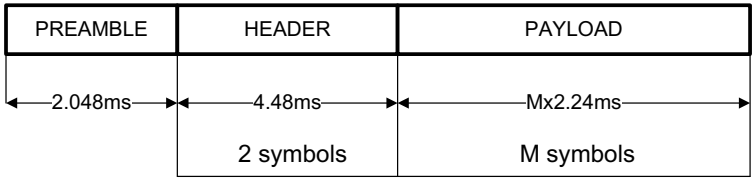
PLC PRIME

- Detailed frame structure (Promotion Needed PDU):

MAC



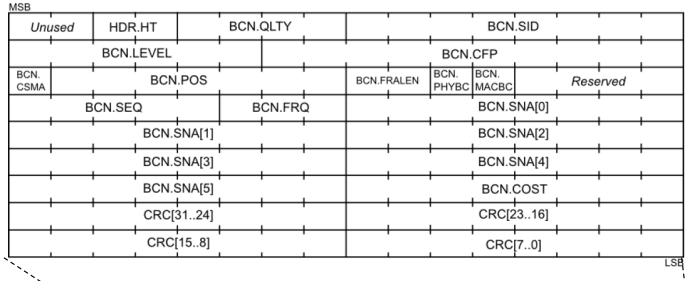
PHY



PLC PRIME

- Detailed frame structure (Beacon PDU):

MAC



PHY