Recent developments on the international standardization of Narrowband PLC for Smart Grid applications

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Outline

Smart Grid

- Comms are key
- Drives converge
- Importance of global standards

ITU and IEC efforts

ITU-T work in smart grid

The ITU-T family of NB-PLC standards

Some considerations

Conclusions

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Role of ICT in Smart Grid

- **The fundamental challenge in power grids is to ensure the balance of generation and demand**
- **The fundamental challenge in the Smart Grid is to ensure balance of generation and demand when integrating all those technologies that are aimed at addressing in a sustainable manner energy independence and modernization of the power grid:**
  - Utility scale RES feeding into the transmission system
  - DER feeding into the distribution system
  - Plug-in Electric Vehicles (PEV)
  - Demand Side Management (DSM)
  - Demand Response (DR)
  - Consumer participation
  - Storage

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Role of ICT in Smart Grid

- **The Power Grid is a commodity delivery system where the commodity (electric power) has a production-to-consumption cycle time of zero: generation, delivery and consumption happen *all at the same* time!**
  - This creates unique challenges in sensing, communications, and control because electrical power moves as fast as communication signals do

- **These challenges will escalate with the integration of RES, DER, P(H)EV, DSM, storage, consumer participation, etc.**

- **Balancing generation and demand of this "perfect just-in-time system" will then require the integration of additional protection and control technologies that ensure grid stability - not a trivial patch to the current power grid control network (SCADA) and a design challenge**
  - Combined problem of communications, sensing and control!

Smart Grid Drives Convergence

- **The "union" between the Communications and Power industries is still unconsummated, but it will happen as building a new ICT infrastructure is very costly**
- **Telecom industry and service providers have a very important role in the smart grid**
  - Cloud based hosted energy service providers will reach the home also via existing broadband access technologies
  - Broadband access has a role in demand side management
    - Especially DSL, as it provides dedicated (non-shared) channels
- **Another driver for convergence is that Smart Grid does not end at the meter but it enters the home.**
  - Many aspects of the Smart Grid are directly related to the availability of a home networking and consumer participation is key in demand side management programs
  - This will also shape the future of the Consumer Electronics industry through energy efficiency

Smart Grid Requires Global Standards

- **The power grid often crosses international or jurisdictional boundaries, but applications and devices must interoperate regardless of those boundaries**
- **The Telecom/Power/CE convergence for the Smart Grid will drive a new echo-system of products and this must happen under the auspices of International SDOs**
- **ITU-T can have a major role in facilitating the convergence of the communications, power, and CE worlds**
- **Cooperation between the major International SDOs is key to success!!**

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IEC and ITU intensify cooperation

- **Global coordination on Smart Grid is taking place in IEC Strategic Group 3**
  - IEC SG 3 comprises expertise from all activities in IEC
  - ITU-T now has full representation and participation in SG3
- **PC118: Smart Grid User Interface**
  - Created in Nov. 2011, with Richard Schomberg (EDF) as Chair and Wang Like (China Electric Power Research Institute (CEPRI) as secretary
  - Scope: Standardization of information exchange for demand response and connecting demand side equipment/systems into the smart grid
  - ITU-T proposal for coordinating and contributing ICT related aspects has been approved
- **Cooperation via ITU-T Joint Coordination Activity on Smart Grid and Home Networking (JCA SG&HN)**

Joint Coordination Activity (JCA SG&HN)

- Created in January 2012
- The scope is the coordination, both inside and outside of the ITU-T, of standardization work concerning all network aspects of Smart Grid and Home Networking
- Convenors:
  - Dick Stuart, Lantiq
  - Les Brown, Lantiq
  - Stefano Galli, ASSIA
- Details available at:

http://www.itu.int/en/ITU-T/jca/SGHN/Pages/default.aspx

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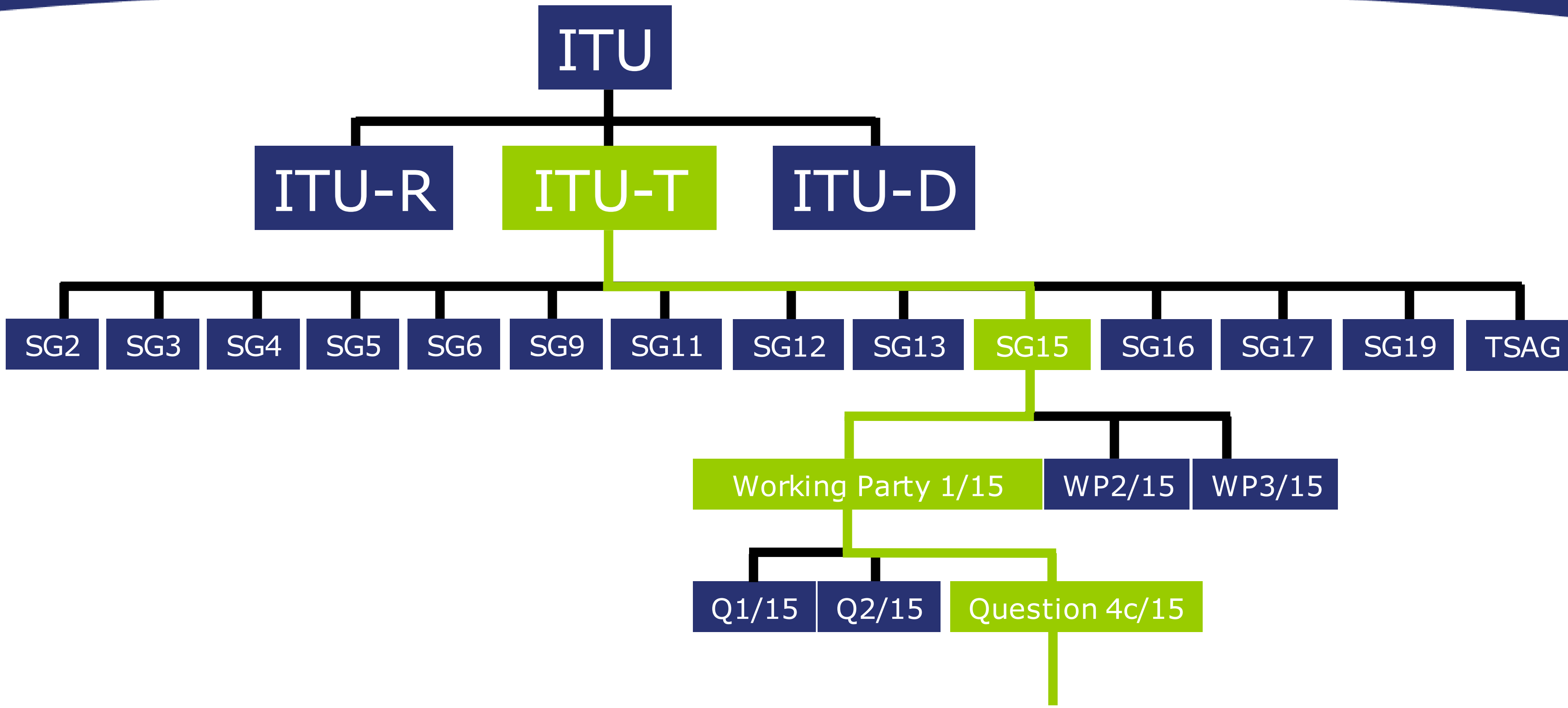
New ITU-T Group on Smart Grid Comms



Communications for Smart Grid
Rapporteur: Stefano Galli (ASSIA)

<u>Scope</u>: Physical layer, data link layer, network layer, and transport layer communications protocols in support of Smart Grid applications

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Smart Grid Related Activities in ITU-T

Items	SGs and aspects	
(1) M2M	FG M2M	Service Layer use cases, requirements, APIs and protocols for healthcare and other application
	SG13	Q3/13 USN, MOC Q12/13 Ubiquitous networking (object to object communication)
	SG15	Q1/15 IP home network
	SG16	Q25/16 USN applications and services
(2) Smart metering	SG15	Q4c/15 Communication platform and PHY/DLL aspects of smart metering
(3) Vehicle charging and communication	CITS	Collaboration on ITS Communication Standards http://www.itu.int/en/ITU-T/extcoop/cits/
	SG13	Q12/13 networked vehicle
	SG15	Q4c/15 PEV communications
	SG16	Q27/16 Vehicle gateway platform for telecommunication/ITS services /applications
(4) Home networking	SG13	Q12/13 Next generation home network
	SG15	Q1 and Q2/15 IP home network and access network QoS Q4b/15 Broadband in-premises networking Q4c/15: Home networking related Smart Grid communications
	SG16	Q21/16 home network services
(5) Energy saving network	SG13	Q21/13 Future network
(6) Smart Grid	SG15	Q4c/15 Smart Grid communications
(7) Security	SG17	Cybersecurity

Status of ITU-T NB-PLC Recs

- **ITU has given final approval to a *family* of next generation OFDM-based NB-PLC international standards:**
  - Rec. G.9955 (PHY) approved in 12/2011
  - Rec. G.9956 (DLL) approved in 11/2011
- **Low complexity OFDM-based NB-PLC technology optimized for Smart Grid and home automation, addresses both access (low/medium voltage distribution lines) and in-home applications at frequencies below 500 kHz**
- **G.9955 and G.9956 contain the specifications of three separate and self-contained NB-PLC standards:**
  1. **G.hnem**: a new NB-PLC technology developed by ITU-T in cooperation with members of the G3-PLC and PRIME Alliances;
  2. **G3-PLC**: an established and field-proven NB-PLC technology contributed by members of the G3-PLC Alliance
  3. **PRIME**: an established and field-proven NB-PLC technology contributed by members of the PRIME Alliance
- **See also ITU Press Release: http://www.itu.int/net/pressoffice/press_releases/2011/CM16.aspx**

Structure of ITU-T Recs

- **Structure of G.9955 (PHY):**
  - Main body G.hnem solution with several bandplans including FCC and CENELEC bands
  - Normative Annexes
    - G3-PLC CENELEC A
    - PRIME CENELEC A
    - G3-PLC FCC
  - Publicly available: http://www.itu.int/rec/T-REC-G.9955
- **Structure of G.9956 (DLL):**
  - Main body G.hnem
  - Normative Annexes
    - G3-PLC
    - PRIME
  - Publicly available: http://www.itu.int/rec/T-REC-G.9956

PRIME Cen A (ITU-T G.9955/6)

- **Operates over 42–89 kHz (Cenelec A)**
- **OFDM with:**
  - 97 active carriers (1 pilot), 512-IFFT size, 488.3 Hz spacing
  - OFDM symbol duration: 2240 us
  - Guard interval: 192 us
  - Bits per carrier: 1, 2, 3
  - No windowing
- **No robust mode**
- **Differential encoding, per OFDM symbol across the subcarriers**
- **FEC: convolutional encoding (optional)**
- **Interleaving per OFDM symbol**
- **Variable number of OFDM symbols per PHY frame, up to 63**
- **Max “net” PHY frame data rate:**
  - 122.9 kbps (FEC off)
  - 61.4 kbps (FEC on)

G3-PLC Cen A (ITU-T G.9955/6)

- **Operates over: 35.9–90.6 kHz (Cenelec A)**
- **OFDM with:**
  - 36 active carriers, 256-IFFT size, 1.5625 kHz spacing
  - OFDM symbol duration: 695 us
  - Guard interval: 55 us
  - Bits per carrier: 1, 2, 3
  - Windowing: 8 samples
- **Three robust modes (with repetitions)**
- **Classical differential encoding (over time)**
- **FEC: concatenated convolutional and RS (mandatory)**
- **Interleaving over the whole packet**
- **Single RS codeword per PHY frame**
- **Max "net" PHY frame data rate: 46 kbps**

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G.hnem Cen A (ITU-T G.9955/6)

- **Operates over: 35.9–90.6 kHz (Cenelec A)**
- **OFDM with:**
  - 36 active carriers (3 pilots), 128-IFFT size, 1.5625 kHz spacing
  - OFDM symbol duration: 760 us
  - Two guard intervals: 60 us, 120 us
  - Bits per carrier: 1, 2, 3, 4
  - Windowing: 8 samples
- **Robust modes (with repetitions)**
- **Coherent demodulation solution**
- **FEC: concatenated convolutional and RS (mandatory)**
- **Two interleaving modes: over fragment, over AC cycle**
- **Multiple RS codewords per PHY frame**
- **Max "net" PHY frame data rate: 101.3 kbps**

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G3-PLC FCC (ITU-T G.9955/6)

- **Operates over 159.4–478.1 kHz (FCC)**
- **OFDM with:**
  - 72 active carriers, 256-IFFT size, 4.6875 kHz spacing
  - OFDM symbol duration: 231.7 us
  - Guard interval: 18.3 us
  - Bits per carrier: 1, 2, 3
  - Windowing: 8 samples
- **Robust modes (with repetitions)**
- **Classical differential encoding (over time)**
- **FEC: concatenated convolutional and RS (mandatory)**
- **Interleaving over the whole packet**
- **Single RS codeword per PHY frame**
- **Max "net" PHY frame data rate: 207.6 kbps**

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G.hnem FCC (ITU-T G.9955/6)

- **Operates over: 34.4–478.1 kHz (FCC)**
- **OFDM with:**
  - 145 active carriers (12 pilots), 256-IFFT size, 3.125 kHz spacing
  - OFDM symbol duration: 380 us
  - Two guard intervals: 30 us, 60 us
  - Bits per carrier: 1, 2, 3, 4
  - Windowing: 16 samples
- **Robust modes (with repetitions)**
- **Coherent demodulation solution**
- **FEC: concatenated convolutional and RS (mandatory)**
- **Two interleaving modes: over fragment, over AC cycle**
- **Multiple RS codewords per PHY frame**
- **Max "net" PHY frame data rate: 821.1 kbps**

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NB-PLC Comparison

	PRIME (ITU)	G3-PLC (ITU)	IEEE 1901.2	G.hnem (ITU)
Mod.	*t*-diff	*t*-diff	*t*-diff/coh (O)	coherent
Max bits	3	3	3 (diff)/4(coh)	4
GI (us) Cen	192	55	55	60, 120
GI (us) FCC	-	18.3	18.3	30, 60
T_{ofdm} (us) Cen	2240	695	695	760
T_{ofdm} (us) FCC	-	231.7	231.7	380
N_{pilots} Cen	1	0	0/3	3
N_{pilots} FCC	-	0	0/6	12
Max net PHY frame data rate (kbps):				
Cen	**61.4**	**46**	**46/48.1**	**101.3**
FCC	-	**207.6**	**207.6/203.2**	**821.1**

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Observations on Diverse Approaches

- **Very different assumptions on the channel!**
  - Guard interval ranges from 55 us to 192us
  - Interleaving is done over symbol (PRIME), packet (G3/1901.2), over fragment (G.hnem), over AC cycle fraction (G.hnem)
  - Coherent vs non-coherent schemes

- **Different robustness**
  - Use of CC only (PRIME) or concatenated CC+RS
  - Robust modes with no repetitions (PRIME) or repetitions up to 6 (G3/1901.2), or up to 12 (G.hnem)

- **Different PPDU efficiency**
  - Single RS codeword per PHY frame (G3/1901.2) or multiple (PRIME/G.hnem)
  - G3/1901.2: as many fit in a single RS codeword (20~40 symbols)
  - PRIME: up to 63
  - G.hnem: max 250 ms ToW or at most 64 LLC frames (250~300)

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Coherent vs Non-Coherent?

- In differential modulation, the phase of the previous symbol is used as reference of the current symbol
- In AWGN, the SNR gain of coherent versus incoherent reception is nearly 3 dB, while for Rayleigh slow fading channels it is a little bit less than 3 dB (at high SNR)
- Differential modulation copes well with random shifts of the carrier phase, but it does not perform well when the channel is LPTV and is affected by impulsive noise [Umehara-ISPLC'01]
  - Some recent field trials have reported that coherent schemes perform better than non-coherent ones
- Gain of coherent may be also larger than 3 dB when erasures in time and frequency grow
- Current trends seems to prefer coherent schemes, as also IEEE 1901.2 followed ITU in adopting an optional coherent mode
- However, it is necessary to have a channel model to give a definitive answer to this question!

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Putting PLC in the field

- **In the deployment of PLC-enabled nodes, it is important to devise network planning tools to establish coverage**
  - A first element is to have accurate and flexible channel modeling tools, especially statistical ones
  - A second element is a network model based on topological properties of the PL network as the power grid is:
    - The *information source* of the grid
    - The *information delivery system* when PLC are used
- **Both elements have received very little attention in the literature, and the lack of planning tools adds to the confusion of what PLC to choose and deploy**
- **Recent results on these topics are reported here, but mostly for BB-PLC – although tools are also applicable to NB-PLC:**
  - S. Galli, "A Novel Approach to the Statistical Modeling of Wire-line Channels," *IEEE Trans. Commun.*, vol. 49, no 5, May 2011.
  - S. Galli, A. Scaglione, Z. Wang, "For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid," *Proceedings of the IEEE – Special Issue on Smart Grid*, vol. 99, no. 6, June 2011.

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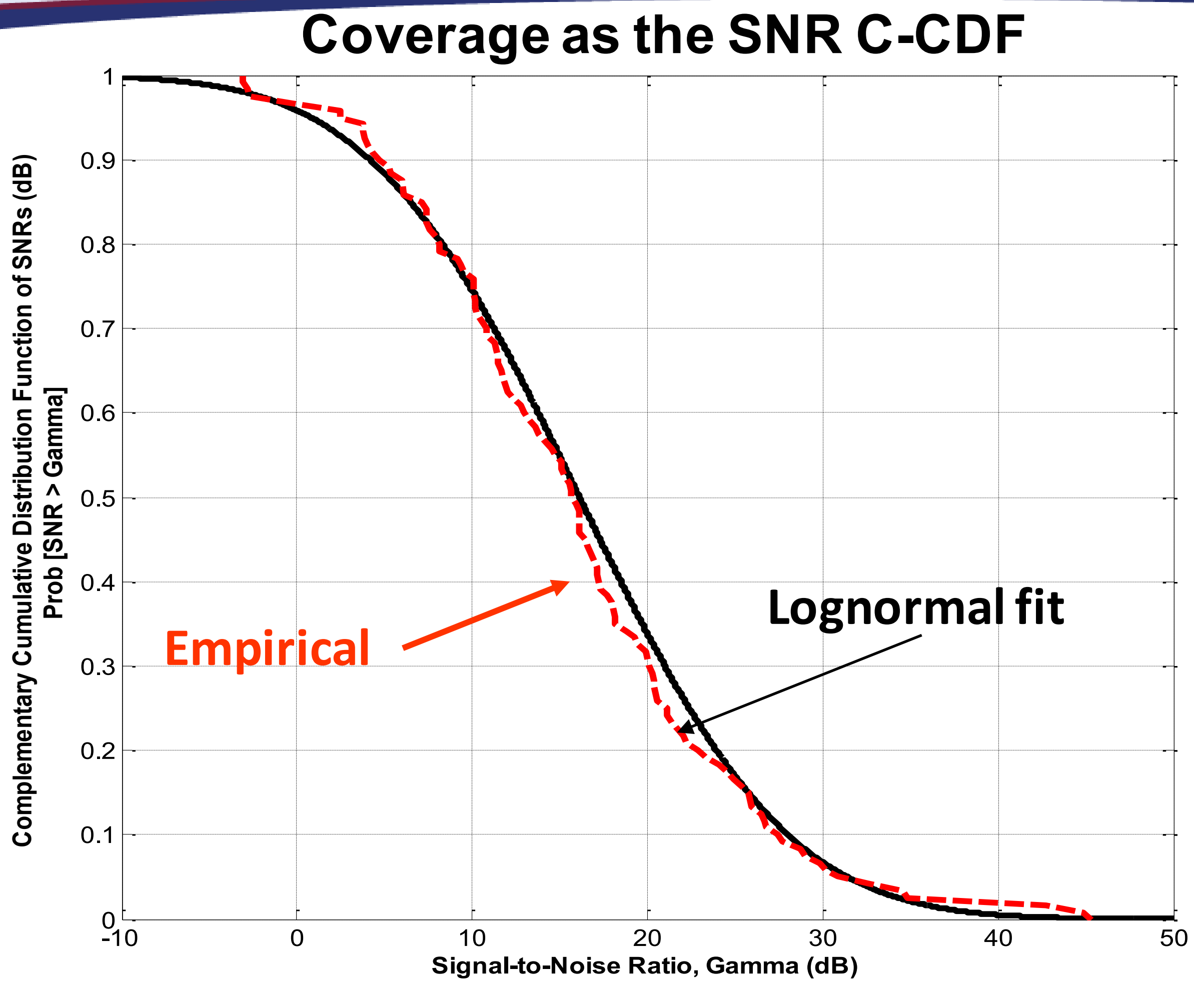
PLC – Statistical Channel Modeling



$$SNR = \frac{P_{TX} \cdot \overline{G}}{P_N}$$

Assumptions:

- P_{TX}: -55 dBm
- P_{Noise}: -120 dBm

S. Galli, "A Simplified Model for the Indoor Power Line Channel," ISPLC 2009

S. Galli, "A Novel Approach to the Statistical Modeling of Wire-line Channels," TCOM 2011

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Conclusions

- **IEC and ITU-T are increasing their efforts in coordination and collaboration in the area of Smart Grid in order to realize global standards**
- **Utilities are starting to join ITU-T**
  - ERDF is in process of joining ITU-T
- **The G.hnem project is being recognized by the industry**
  - G3-PLC Alliance is contributing to Q4c/15 and has also endorsed ITU-T Recommendation G.9955/6 Annex A
  - PRIME Alliance also is contributing to Q4c/15
- **Industry now has the availability of a family of next generation NB-PLC international standards that cover many applications and with distinct characteristics**
- **Further optimization may be difficult as results on the NB-PLC channel are scarce, and no statistical result is available**
- **Recent good papers on the subject (but no channel model!):**
  - M. Nassar, Jing Lin, Y. Mortazavi, A. Dabak, Il Han Kim, B.L. Evans, "Local Utility Powerline Communications in the 3-500 kHz Band: Channel Impairments, Noise, and Standards," IEEE Signal Proc. Mag., Sep'12
  - V. Oksman, J. Zhang, "G.HNEM: The New ITU-T Standard on Narrowband PLC Technology," IEEE Commun. Magazine, Dec. 2011.

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Thank You!

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