



# Energy Fraud and Orchestrated Blackouts

## Issues with Wireless Metering Protocols (wM-Bus)

Black Hat USA 2013, Las Vegas, Aug 1<sup>st</sup> 2013

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## Intro

- ✦ Making Of
- ✦ Smart Grids
- ✦ Smart Metering

## Wireless M-Bus

- ✦ Application
- ✦ Protocol Stack
- ✦ Protocol Overview (Frames, Transport Layer, Data Headers)
- ✦ Protocol Analysis (Privacy, Confidentiality, Integrity)

## Demo

- ✦ Setup
- ✦ Attacks and Issues

## Conclusion



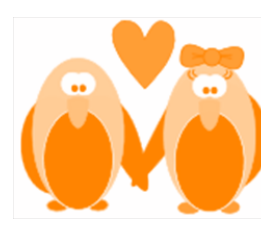
# Intro

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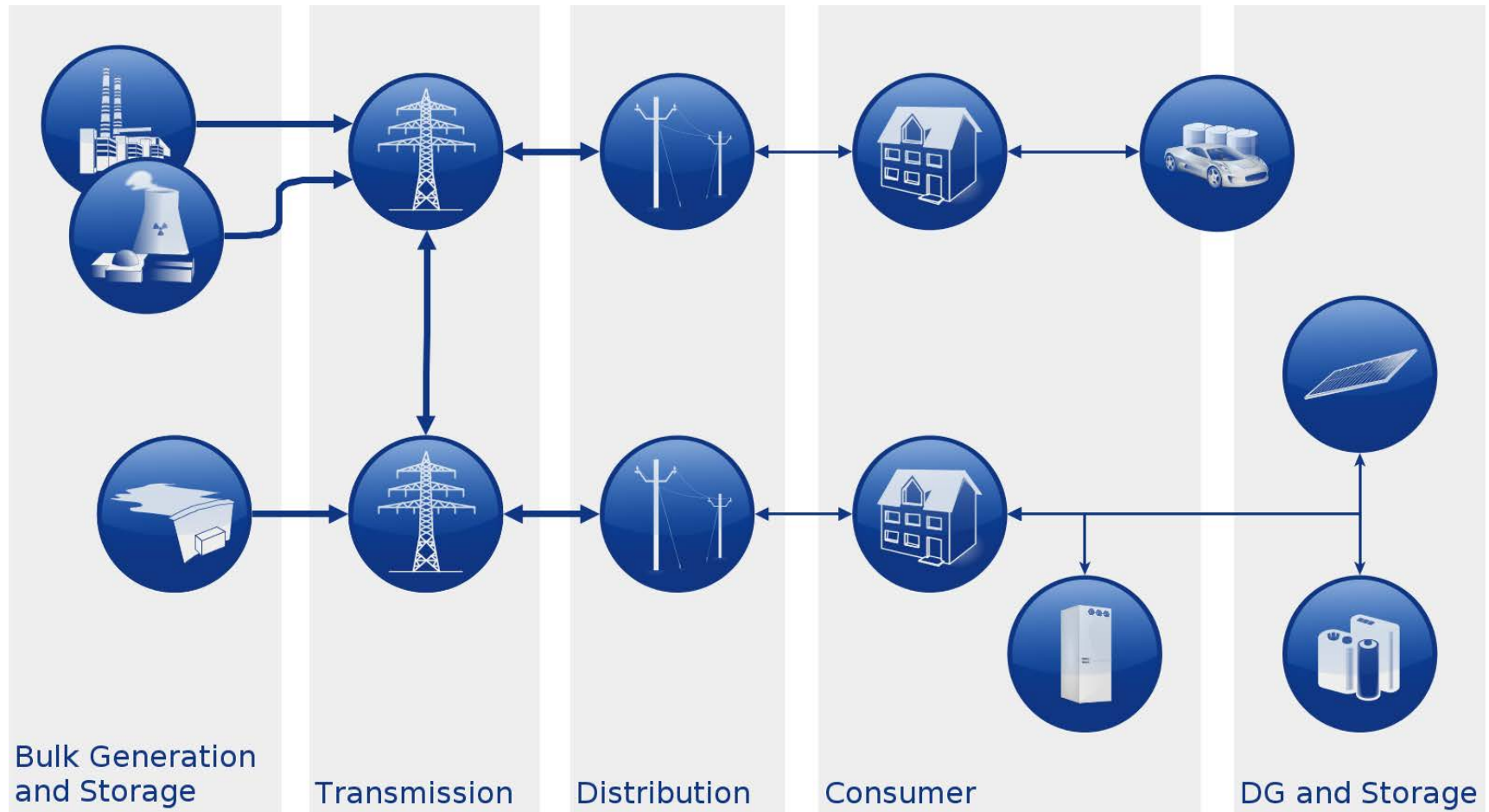
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## Timeline

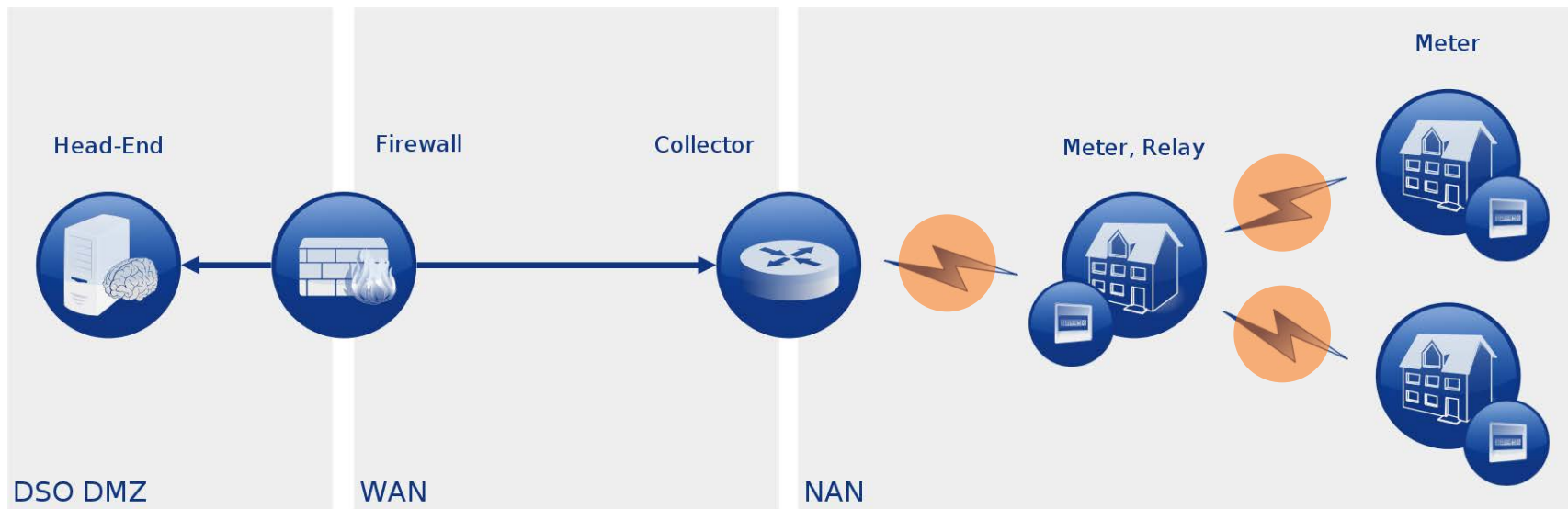
- ✦ Summer 2011: Got attention of wireless M-Bus
- ✦ Autumn 2012: Started MSc thesis
- ✦ X-mas 2012: German BSI/OMS group published „Security Report“
- ✦ X-mas 2012: Short mention of M-Bus being „inadequate“
- ✦ February 2013: Spent some time digging through EN paperwork
- ✦ February 2013: Spent some time in an M-Bus lab environment
- ✦ March 2013: Finished analysis of M-Bus current resp. draft standards
- ✦ March 2013: German BSI mentions wM-Bus security being insufficient
- ✦ Summer 2013: Publication at Black Hat USA



## Smart Grid Blue Print



## Metering Infrastructure Blue Print



## Legend

- ◆ DSO Distribution System Operator
- ◆ NAN Neighbourhood Area Network
- ◆ ● Wireless M-Bus

## Collectors

- ✦ Various Vendors
- ✦ Neuhaus is just an example of a Multi Utility Controller (MUC)

## Support Head-end side

- ✦ GPRS
- ✦ Ethernet (Web Interface)
- ✦ WLAN
- ✦ WiMAX

## Support Meter side

- ✦ Wired Serial (RS-485)
- ✦ Wired M-Bus
- ✦ ZigBee
- ✦ Wireless M-Bus



VARIOMUC-Manager 1.2.3.14

Datei Trennen Short Info Einstellungen Sonderfunktionen Sensoren

- [-] Benutzer
  - ... Gast
  - ... Endanwender
  - ... MUC-Betreiber
  - ... Messstellenbetreiber
  - ... Messdienstleister
  - ... Lieferant
  - ... Hersteller
  - ... LAN/DSL
  - ... IPT
  - ... Service/Kundenschnittstelle

Nr.	Servernummer	Zählernummer	Status
1	000475F72E0F		18.07.2013
2	01242375034010640E	HYD 10400375 Bus-/System-Komponente	18.07.2013
3	01242376034010640E	HYD 10400376 Bus-/System-Komponente	18.07.2013
4	012D2C077194150102	KAM 15947107 Elektrizität	18.07.2013
5	012D2C400649150102	KAM 15490640 Elektrizität	18.07.2013
6	019315773535030002	ELS 03353577 Elektrizität	18.07.2013
7	01A205440000570C37	AMB 57000044 Funkwandler (Zählerseitig)	18.07.2013
8	01A511198105423003	DME 42058119 Gas	18.07.2013
9	01A815000216945802	FMH 94160200 Elektrizität	18.07.2013

	OBIS	OBIS	Wert	Scaler	Einheit	Status	Zeit
440000570C37	8181C78203FF	129-129:199.130.3*255	AMB				
	0000616100FF	0-0:97.97.0*255	0				
	0000600101FF	0-0:96.1.1*255	A2 05 44 00 00 57 0C 37				
	0000600109FF	0-0:96.1.9*255	BMBER wireless Testmodul! T Mode				



## Electricity Meters

- ✦ Various Vendors
- ✦ Kamstrup is just an example

## Interfaces

- ✦ Optical
- ✦ Wired Interfaces
- ✦ GPRS
- ✦ ZigBee
- ✦ Wireless M-Bus

## Functionality

- ✦ Meter reading
- ✦ Pre-payment
- ✦ Tariffs
- ✦ Disconnect



A vertical decorative image on the left side of the slide shows a close-up of a computer keyboard. A magnifying glass is positioned over a yellow sticky note that is placed on one of the keys. The background is a soft-focus view of the keyboard keys.

## Wireless M-Bus

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## Market segment

- ✦ Popular in remote meter reading
  - ✦ Heat, Water, Gas, Electricity
- ✦ 15 million wireless devices deployed (figures from 2010)
- ✦ Mainly spread across Europe

## Usage

- ✦ Remote meter reading
- ✦ Drive-by meter reading
- ✦ Meter maintenance and configuration
- ✦ Becoming popular for smart metering applications
  - ✦ Tariff schemes, real-time-pricing
  - ✦ Demand-response
  - ✦ Pre-payment
  - ✦ Load-limit
  - ✦ Remote disconnect

## Involved Standards

Layer	Standard	Description
Application	prEN 13757-3	M-bus dedicated application layer (specified application layer security)
Network	EN 13757-5	Wireless relaying (optional for meters supporting the router approach)
Data Link	prEN 13757-4	Wireless meter readout (specifies link layer security)
Physical	prEN 13757-4	Wireless meter readout (specifies use of frequency bands)

## Legend

- ✦ EN European Norm
- ✦ pr Draft Standard

The left side of the slide features a vertical decorative image. It shows a close-up of a computer keyboard with light blue keys. A magnifying glass with a silver handle and a clear lens is positioned over the keys, focusing on a yellow sticky note that is placed on top of one of the keys. A solid dark blue vertical bar is on the far left edge of the image.

## Protocol Overview

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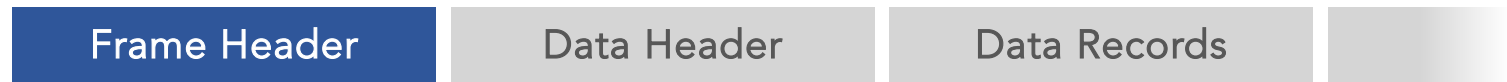
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## Physical Layer

- ✦ Frequency Spectrums
  - ✦ 868 MHz
  - ✦ 434 MHz
  - ✦ 169 MHz
- ✦ Distance
  - ✦ Up to 5 miles (LoS)
- ✦ Line coding (depends on communication mode)
  - ✦ 3 of 6 code (constant-weight code)
  - ✦ Manchester coding
  - ✦ NRZ coding

## Data Link Layer

- ✦ Frames (typical)



- ✦ CRCs
- ✦ Device addressing
- ✦ Specification of data (application layer)
  - ✦ Response
  - ✦ Command
  - ✦ Alerts and Errors...
- ✦ Extended Link Layer
  - ✦ CRCs
  - ✦ Provides encryption at link layer

## First Block (Frame Header)

Example Capture (Sent by meter, CRCs removed)

```
1E 44 2D 2C 07 71 94 15 01 02 7A B3 00 10 85 BF
5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8
```

Field	Value	Interpretation
Length	1E	30 bytes frame length (exclusive length byte)
Control	44	Indicates message from primary station, function send/no reply (SND-NR)
Manuf. ID	2D 2C	Coded for Kamstrup (KAM) calculated as specified in prEN 13757-3. ID is managed by the flag association.
Address	07 71 94 15 01 02	Identification: 15 94 71 07 (little-endian) Device Type: 02 (electricity meter) Version: 01



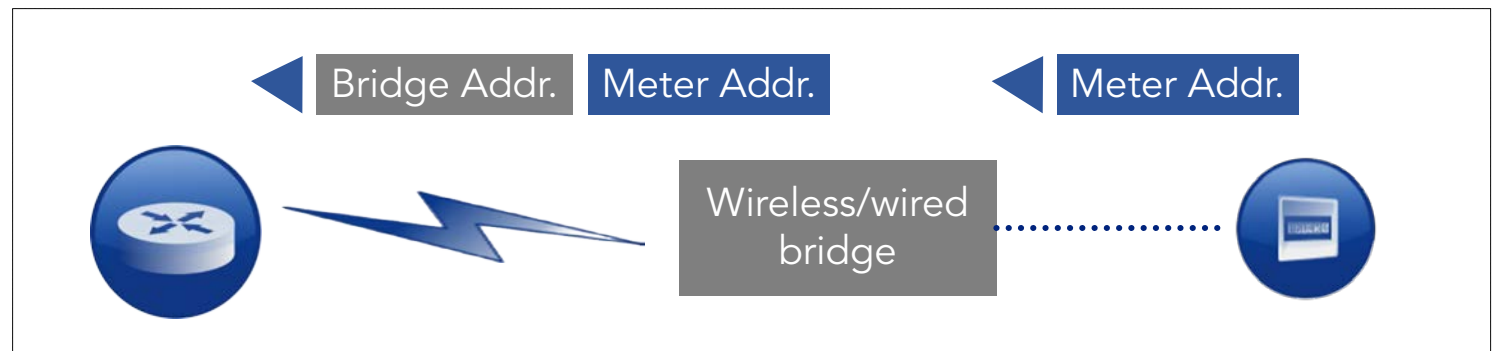
## Data Header Types

Frame Header

Data Header

Data Records

- ✦ No header
- ✦ Short header
  - ✦ Indicates access number
  - ✦ Signals errors and alerts
  - ✦ Indicates encryption mode
- ✦ Long header
  - ✦ Additionally signals addresses behind bridges or virtual devices



## Data Header Example

Example Capture (Sent by meter, CRCs removed)

```
1E 44 2D 2C 07 71 94 15 01 02 7A B3 00 10 85 BF
5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8
```

Field	Value	Interpretation
Access number	B3	Current access number is 179. The standard mandates to choose a random number on meter start. The standard suggests to use timestamps and sequence counters since ACC is insufficient to prevent replay.
Status field	00	Message is meter initiated and there are no alarms or errors.
Configuration	10 85	Encryption mode is 5 <sub>h</sub> which is AES-128 in CBC mode. 10 <sub>h</sub> indicates a single encrypted block containing meter data (without signature). The field further indicates a short window where the meter listens for requests (8 <sub>h</sub> )

## Data Records

Frame Header

Data Header

Data Records

- ◆ Structured using data information fields (DIF) and value information fields (VIF) incl. relevant extensions (DIFE, VIFE)

## Data Record Example

04 83 3B 08 34 05 00

Field	Value	Interpretation
DIF	04	Instantaneous readout value, no extension fields
VIF	83	Primary VIF, Unit: Energy $10^0$ Wh, has extension (VIFE0)
VIFE0	3B	Forward flow contribution only
Data	08 34 05 00	The value is coded LSB first and it represents a value of 341000 respectively: 341 kWh

# Wireless M-Bus Sniffer



Protocol sniffers display wireless M-Bus data record contents provided you know the key. The standard suggests "at least 8 bytes of the key shall be different for each meter"

```
cbrunsch@tortuga: ~/Dev/scambus
cbrunsch@tortuga:~/Dev/scambus$ ./scanner.py -vv -i /dev/ttyUSB3
Aug 01 19:24:03 AMB 57 00 00 44 SND-NR Records: 2
--
CI Detail:      72 (EN 13757-3 Application Layer with long Transport Layer, SND-
header:        long header
has errors:    False
access:        No access
config word:   05 30
mode:          5 (AES encryption with CBC; IV is not zero)
iv:            A2 05 44 00 00 57 0C 37 58 58 58 58 58 58 58
key:           CA FE BA BE 12 34 56 78 9A BC DE F0 CA FE BA BE
--
DIFs:          0E (Instantaneous value, 12 digit BCD)
VIFs:          13 (Volume l)
Value:         00 00 00 00 21 36
--
DIFs:          0D (Instantaneous value, variable length)
VIFs:          FD 11 (Second extension of VIF-codes)
Value:         41 4D 42 45 52 20 77 69 72 65 6C 65 73 73 20 54 65 73 74 6D 6F 64 75 6C
0 4D 6F 64 6F
```

The background of the slide is a close-up photograph of a computer keyboard. A magnifying glass is placed over the keyboard, focusing on a yellow sticky note that is stuck to a key. The image is slightly blurred, giving it a professional and technical feel.

# wM-Bus Protocol Analysis

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## Dedicated Application Layer (DAL) Encryption Modes

- ✦ 0 no encryption
- ✦ 1 reserved
- ✦ 2 DES in CBC mode, zero IV
- ✦ 3 DES in CBC mode, non-zero IV
- ✦ 4 AES-128 in CBC mode, zero IV
- ✦ 5 AES-128 in CBC mode, non-zero IV
- ✦ 6 reserved for future use
- ✦ 7ff reserved

## Extended Link Layer (ELL) Encryption Modes

- ✦ 0 no encryption
- ✦ 1 AES-128 in CTR mode

## Are we safe with AES?



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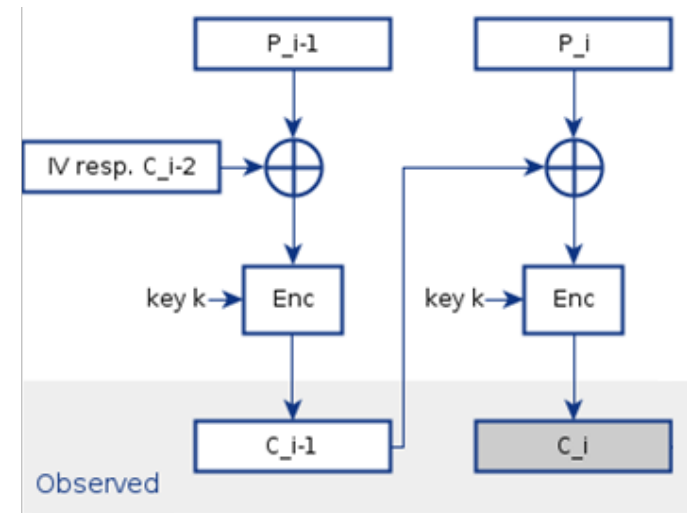
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# Are we safe with AES?



## Encryption Mode 4 (DAL)

- ✦ AES-128 in CBC mode
- ✦ All-zero IV
- ✦ Uses static key  $k$
- ✦  $C_1 = \text{Enc}_k(P_1 \oplus \text{IV})$   
 $= \text{Enc}_k(P_1 \oplus 00\ 00 \dots 00\ 00)$   
 $= \text{Enc}_k(P_1)$
- ✦ Equal PT result in same CT



## Standard workaround

- ✦ Standard mandates to prefix value with date and time record
- ✦ Date and time (record type F) maximum granularity is minutes

## Side note

- ✦ Type I and J records allow for a granularity of seconds



# Is encryption mode 5 our friend?



## Encryption Mode 5 (DAL)

- ✦ AES-128 in CBC mode
- ✦ Non-zero IV
- ✦ Uses static key k
- ✦ IV built from frame info and data header

## Mode 5, IV Example

Example Capture (Sent by meter, CRCs removed)

```
1E 44 2D 2C 07 71 94 15 01 02 7A B3 00 10 85 BF
5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8
```

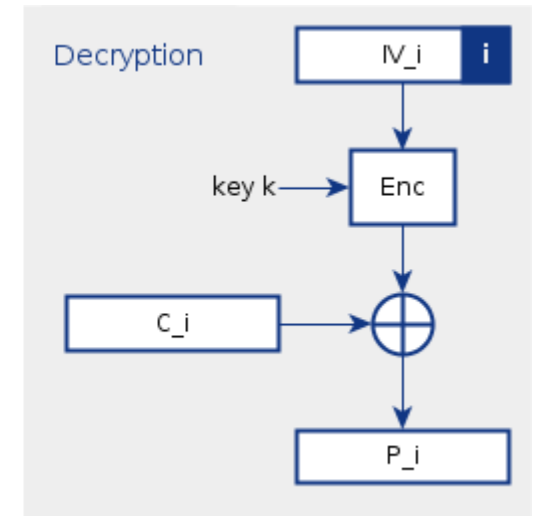
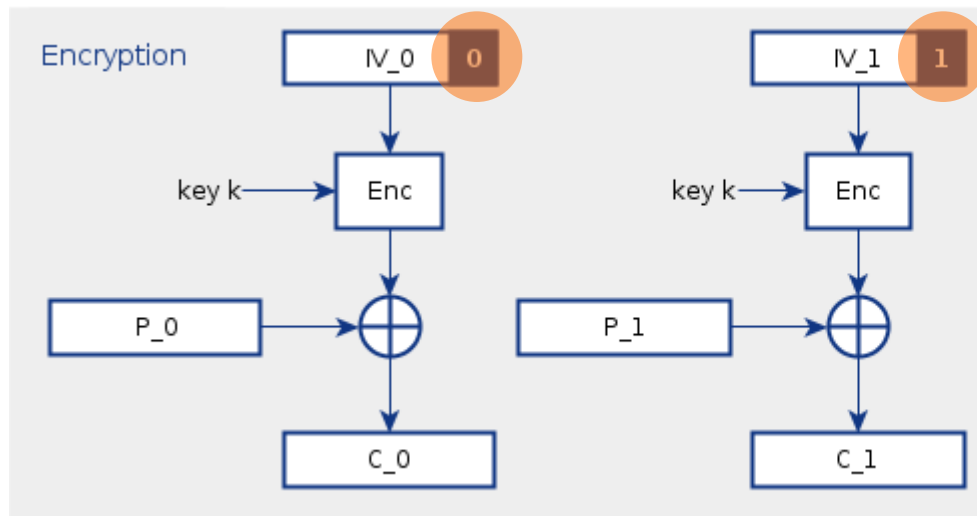
Initialization Vector (IV)															
Manuf.		Address						Padding with Access Number							
2D	2C	07	71	94	15	01	02	B3	B3	B3	B3	B3	B3	B3	B3

# How about Counter Mode?



## Encryption Mode 1 (ELL)

- ◆ AES-128 in CTR mode



# How about Counter Mode?



## Keystream repetition in CTR mode

$$C_a = \text{Enc}_k(\text{IV}) \oplus P_a$$

$$C_b = \text{Enc}_k(\text{IV}) \oplus P_b$$

## Apply Mathemagic

$$P_a \oplus P_b = C_a \oplus C_b$$

## Example of Keystream Repetition

$$P_a = \quad 04 \ 83 \ 3B \ \mathbf{08} \ 34 \ 05 \ 00 \ 2F\dots \quad (341'000 \ \text{Wh})$$

$$P_b = \quad 04 \ 83 \ 3B \ \mathbf{14} \ 34 \ 05 \ 00 \ 2F\dots \quad (341'012 \ \text{Wh})$$

$$P_a \oplus P_b = 00 \ 00 \ 00 \ \mathbf{1C} \ 00 \ 00 \ 00 \ 00\dots$$

$$C_a \oplus C_b = 00 \ 00 \ 00 \ \mathbf{1C} \ 00 \ 00 \ 00 \ 00\dots$$

# How about Counter Mode?



We observed a difference of 0x1C. So what?

Think about the construction of 0x1C out of two values

$$\begin{aligned} \text{Max. difference: } & 1\ 1100 = 28 \\ & -0\ 0000 = 0 \\ & = \mathbf{28\ Wh} \end{aligned}$$

$$\begin{aligned} \text{Min. difference: } & 1\ 0000 = 16 \\ & -0\ 1100 = 12 \\ & = \mathbf{4\ Wh} \end{aligned}$$

Consumption must have changed between 4 and 28 Wh

# How about Counter Mode?



## IV in encryption mode 1

Manuf.	Address	CC	SN	FN	BC
2 bytes	6 bytes	1 byte	4 bytes	2 bytes	1 byte

- ✦ CC Signal communication direction, prioritise frames ...
  - ✦ SN Encryption mode, time field, session counter (4 bits)
  - ✦ FN Frame number
  - ✦ BC Block counter
- 
- ✦ Predictable IVs result in 85-bits security due to TMTO

## How to get the key stream to repeat?

- ✦ Cause device to reuse the same IV
- ✦ If someone could adjust the device time the IV could be repeated

# Can we adjust the device time?



## Encryption in Special Protocols

- ◆ Alarms and errors
  - ◆ Signalled within status byte
  - ◆ Header is not subject to encryption
- ◆ Application resets (CI 50<sub>h</sub>)
  - ◆ Special upper layer protocol
  - ◆ Security services of the DAL and ELL do not apply
- ◆ Clock updates
  - ◆ Special upper layer protocol
  - ◆ Set, add and subtracts (TC field)

CI	Long Data Header	Check Bytes	TC	Payload	Cmd Verify
1 byte	12 bytes	2F 2Fh	1 byte	9 byte	2F 2F 2F 2Fh

## Issues with message integrity?



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## General

- ✦ There are two mention on how one could approach authentication. However there are neither authentication methods nor protocols specified

## DAL Integrity Protection

- ✦ CRCs
  - ✦ There are CRCs at the frame level
  - ✦ CRCs are not considered integrity protection
- ✦ Signatures
  - ✦ Encryption mode 5 and 6 can signal digitally signed billing data
  - ✦ Not widely used => due to meter display has priority
- ✦ MACs
  - ✦ Not available

## Manipulation of Ciphertexts or IVs

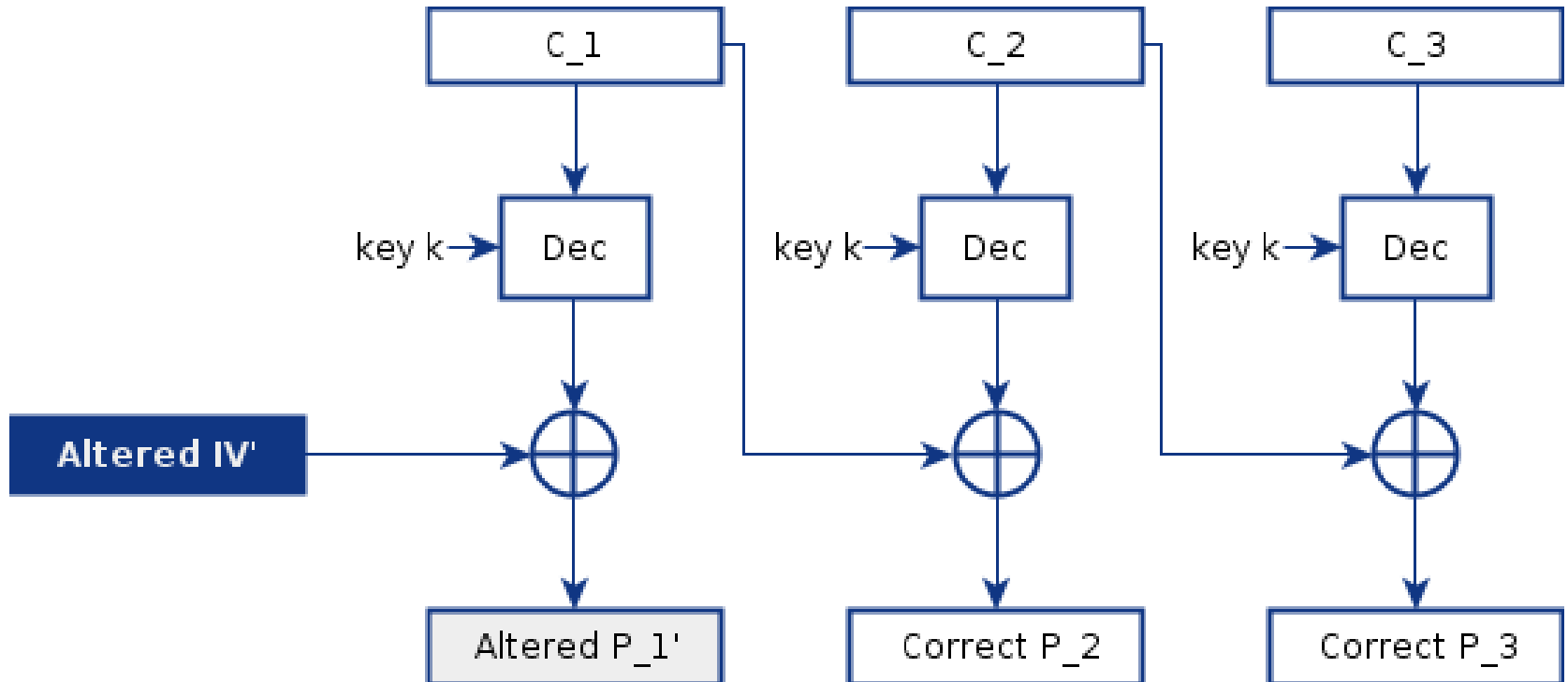
- ✦ In CBC mode, the manipulation of ciphertexts is pointless
- ✦ Manipulation of the IV is difficult but feasible



# IV Manipulation in CBC



## CBC Mode of Decryption



## Feasibility of IV manipulation

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	
IV	Manuf. ID		Device Address				Vers.	Type	ACC	ACC	ACC	ACC	ACC	ACC	ACC	ACC	ACC
P1	Leading 2F		DIF	VIF	VIFE	Consumption Value			Trailing 2F								

## Issues

- ✦ Manipulation of manufacturer or address => key not found
- ✦ Manipulation of version, type => key not found (receiver specific)
- ✦ Manipulation of ACC => destroys trailing 2F (receiver specific)
- ✦ What if devices share the same key?

## Example of Consumption Value Manipulation

$$P_1' = \text{Dec}_k(C_1) \oplus IV' \Rightarrow \text{Dec}_k(C_1) = P_1' \oplus IV' = P_1 \oplus IV$$

$$P_1' = P_1 \oplus IV \oplus IV'$$

## Precondition

- Original value read from meter display 341 kWh (08 34 05 00 )

## Calculate Plaintext $P_1'$

$P_1$	2F	2F	04	83	3B	<b>08</b>	<b>34</b>	<b>05</b>	<b>00</b>	2F	2F	2F	2F	2F	2F	2F
IV	2D	2C	07	71	94	15	01	02	B3	B3	B3	B3	B3	B3	B3	B3
IV'	2D	2C	07	71	94	15	01	<b>05</b>	B3	B3	B3	B3	B3	B3	B3	B3
$P_1'$	2F	2F	04	83	3B	<b>08</b>	<b>34</b>	<b>02</b>	<b>00</b>	2F	2F	2F	2F	2F	2F	2F

## Result

- $P_1'$  144'392 Wh (08 34 02 00)

## Partial Encryption

- ✦ Dedicated Application Layer allows for partial encryption
- ✦ How does the receiver handle doubled data records?

## Expansion Attack Example

Value in CT: 04 83 3B 08 34 **05** 00 (341'000 Wh)

**1E** 44 2D 2C 07 71 94 15 01 02 7A B3 00 10 85 **BF**  
**5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8**

Value attached: 04 83 3B 08 34 **02** 00 (144'392 Wh)

**25** 44 2D 2C 07 71 94 15 01 02 7A B3 00 10 85 **BF**  
5C 93 72 04 76 59 50 24 16 93 27 D3 03 58 C8 **04**  
**83 3B 08 34 05 00**

## ELL Integrity Protection

- ✦ CRC at the frame level
- ✦ Another CRC at the ELL level (subject to encryption)
- ✦ No MACs, no signatures

## ELL CRC calculation

Frame Header

ELL Header

Encrypted Data

CRC		DIF	VIF	VIFE	CMD
CC	22	01	FD	1F	01

# How to easily calculate the CRC



## Data Link Layer: CRC calculation using reveng

```
cbrunsch@tortuga: ~/Documents/rhul/thesis/software/reveng-1.1.0
$ ./reveng -h
CRC RevEng, an arbitrary-precision CRC calculator and algorithm finder
....
Copyright (C) 2010, 2011, 2012, 2013 Gregory Cook
This is free software; see the source for copying conditions. There
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PU
Version 1.1.0 <http://reveng.sourceforge.
$
$ ./reveng -D | grep 13757
width=16 poly=0x3d65 init=0x0000 refin=false refout=false xorout
=0xc2b7 name="CRC-16/EN-13757"
$
$ ./reveng -m CRC-16/EN-13757 -c 01FD1F01
cc22
$ ./reveng -m CRC-16/EN-13757 -c 01FD1F00
f147
$
```

## ELL Manipulation Example

$P_a =$  CC 22 01 FD 1F 01 (On Command)

**$P_b =$  F1 47 01 FD 1F 00 (Off Command)**

$C_a =$  E7 8E 1B 7B 9D 86 (Intercepted Ciphertext)

$C_b = C_a \oplus P_a \oplus P_b$

$C_b =$  E7 8E 1B 7B 9D 86  $\oplus$

CC 22 01 FD 1F 01  $\oplus$

F1 47 01 FD 1F 00

**$C_b =$  DA EB 1B 7B 9D 87 (Manipulated Ciphertext)**

# Which messages are affected?

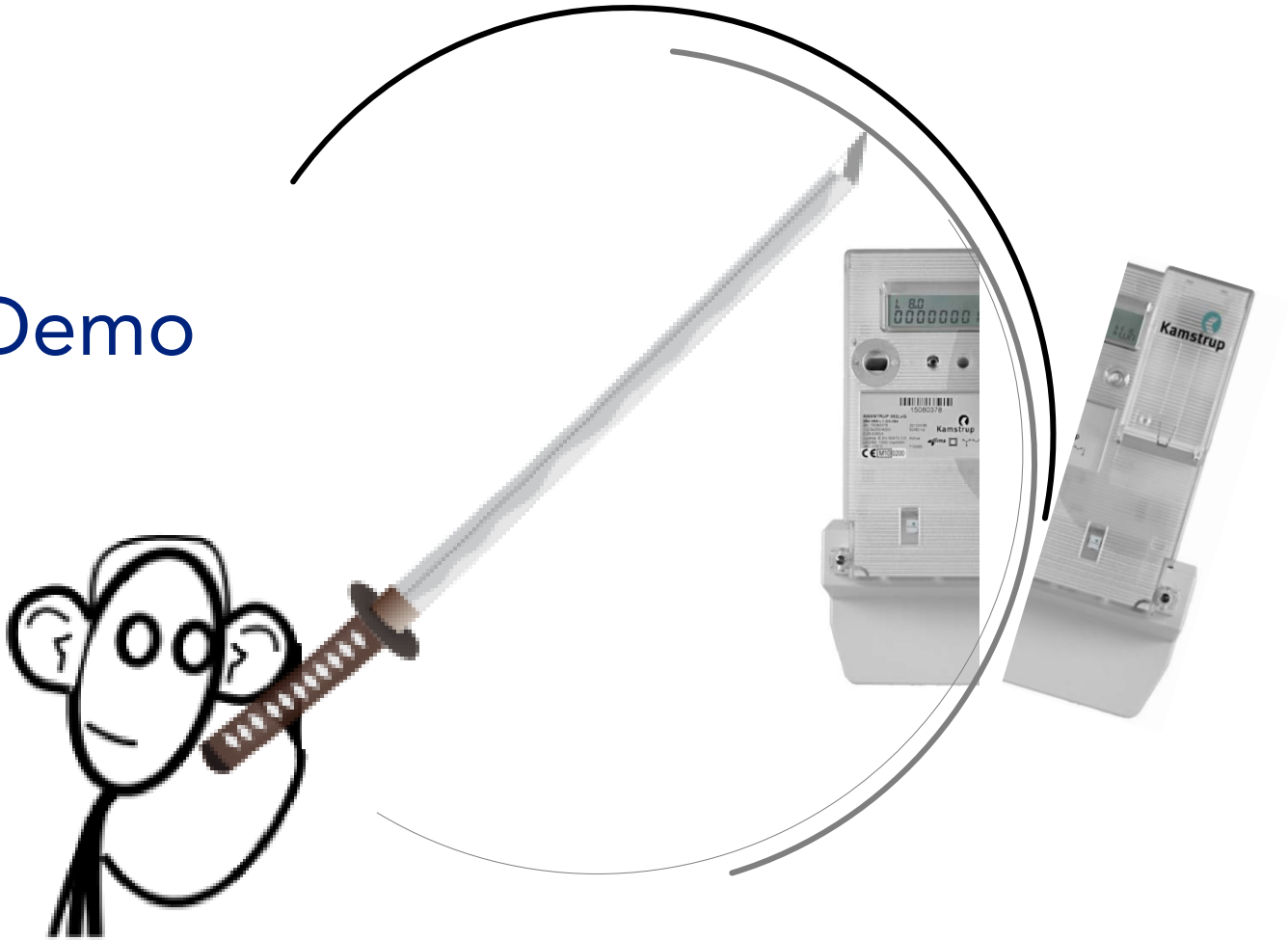


## Integrity with Special Protocols

- ✦ No integrity protection at all
  - ✦ Alarms and errors
  - ✦ Application resets
  - ✦ Clock synchronization
  - ✦ Commands
  - ✦ Network management
  - ✦ Precision timing



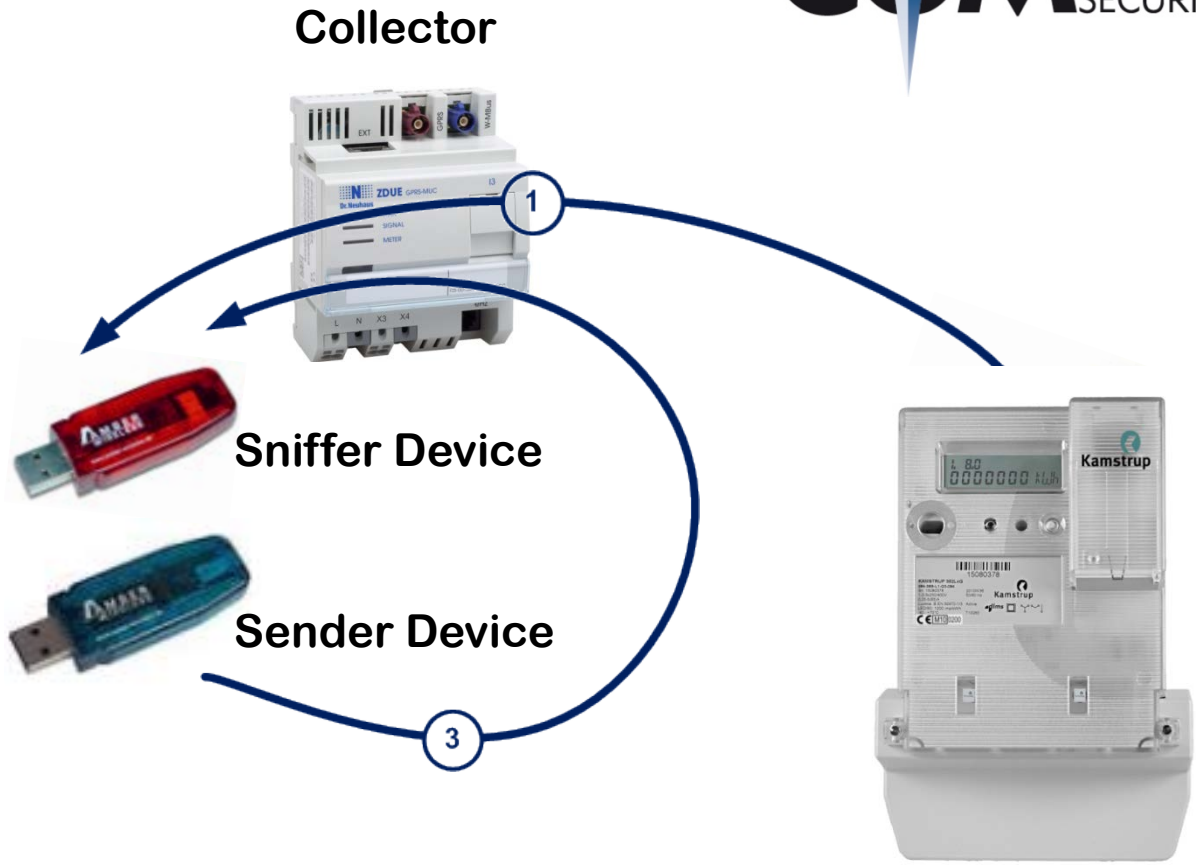
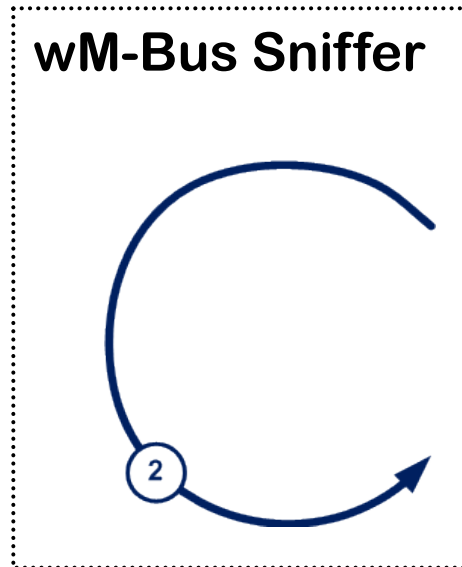
# Demo



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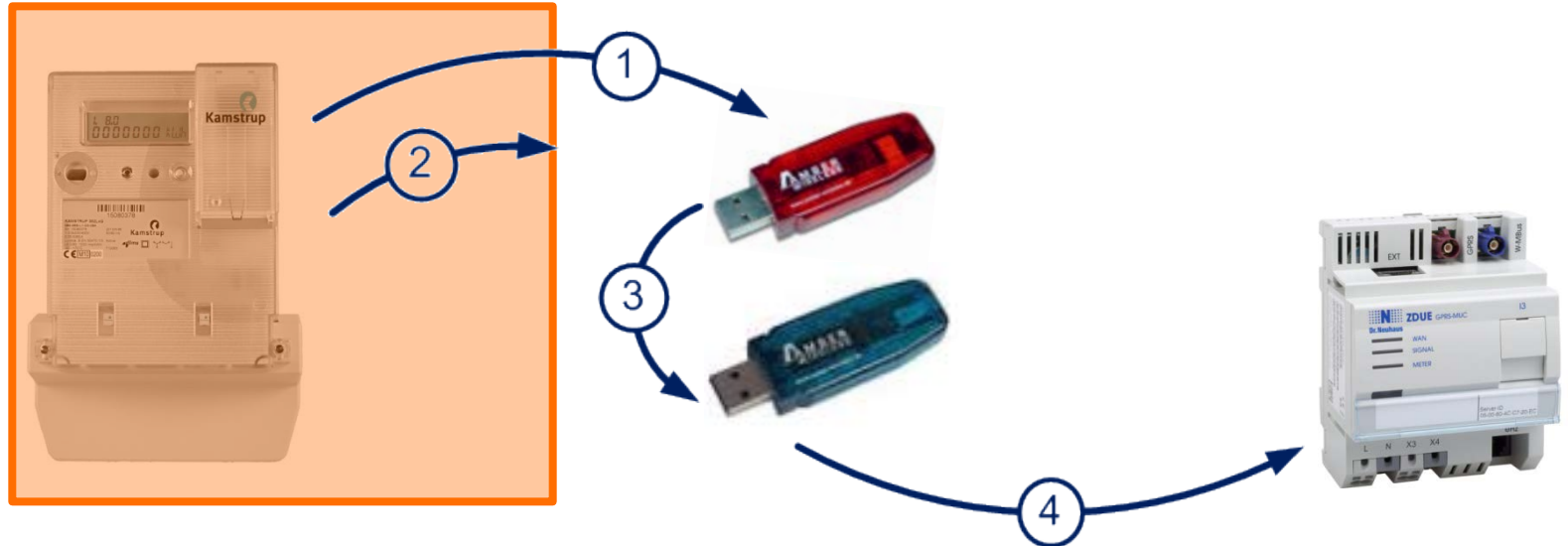
## Setup



## Hardware

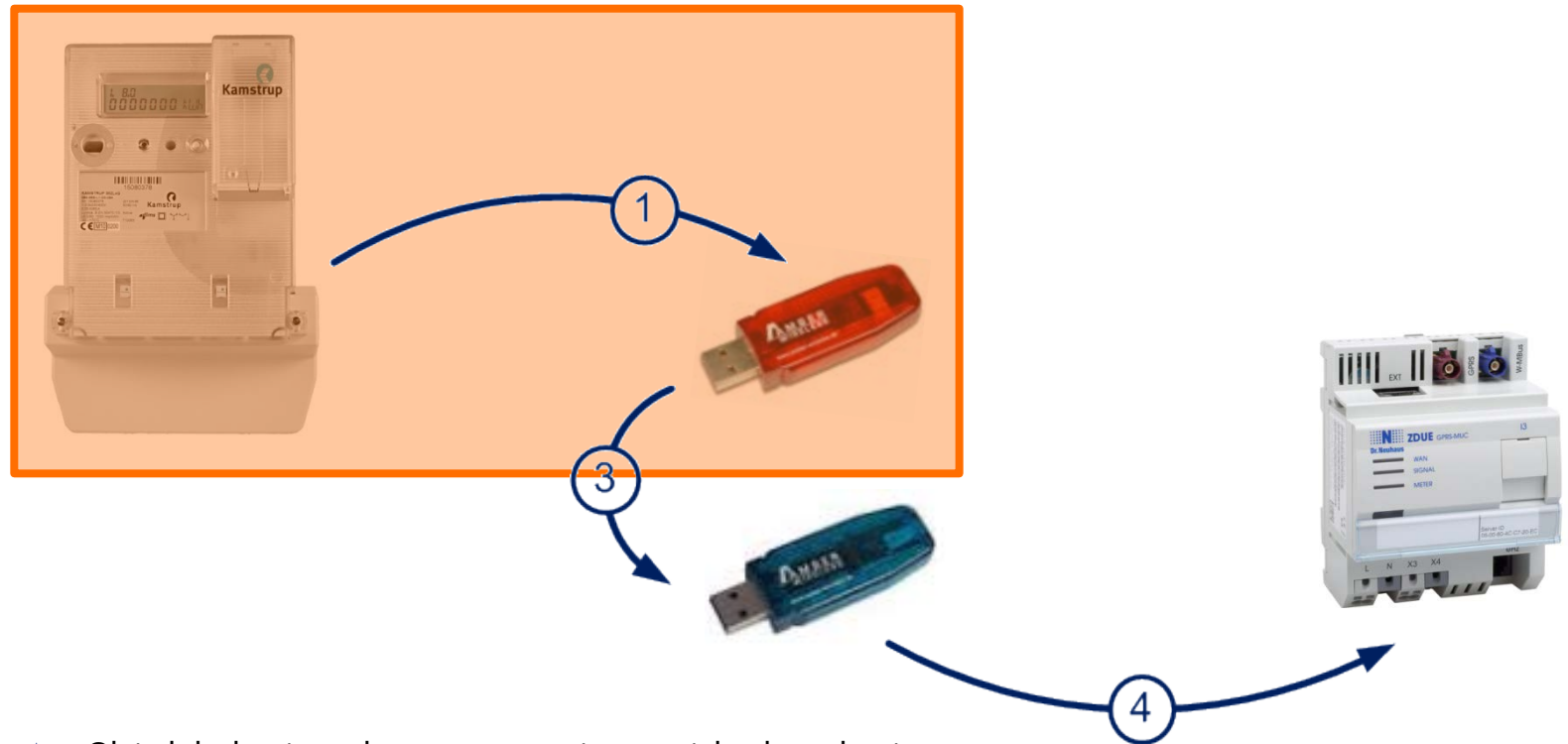
- ★ Amber Sticks <http://amber-wireless.de/406-1-AMB8465-M.html>
- ★ TI Transceiver <http://www.ti.com/lit/ds/symlink/cc1101.pdf>
- ★ TI App Note <http://www.ti.com/lit/an/swra234a/swra234a.pdf>

## Shield and Replay I



- ✦ Capture messages from original device
- ✦ Shield device and replay messages

## Shield and Replay II



- ◆ Shield device, have a receiver with the device
- ◆ Submit messages to collector at maybe lower pace

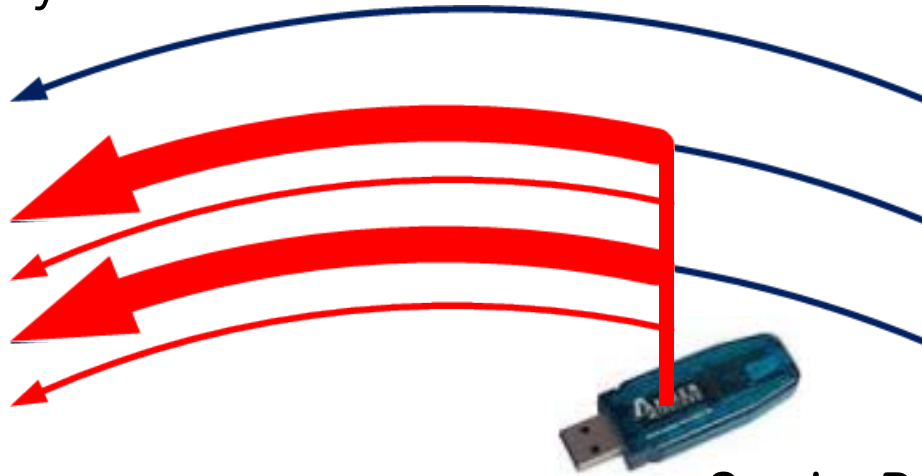
# Issues with Packet Replay



## Jam and Replay



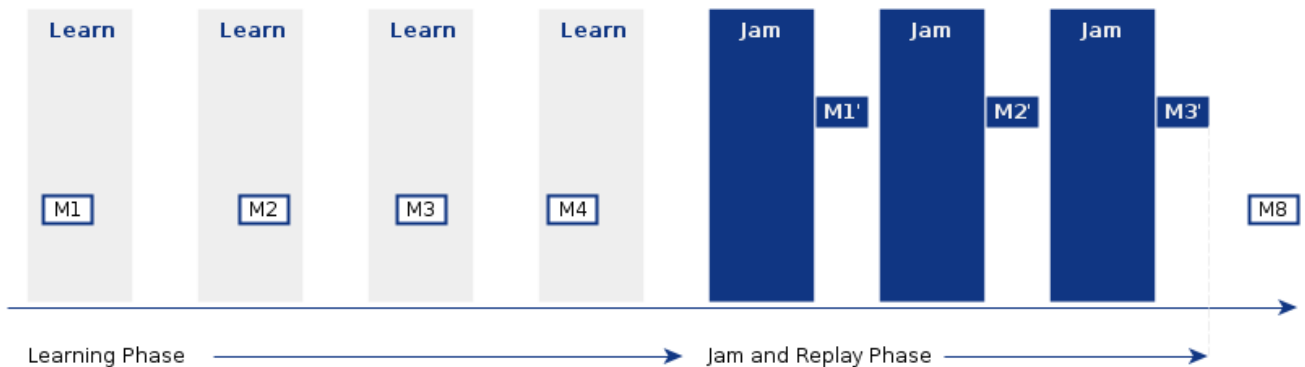
Collector



Sender Device



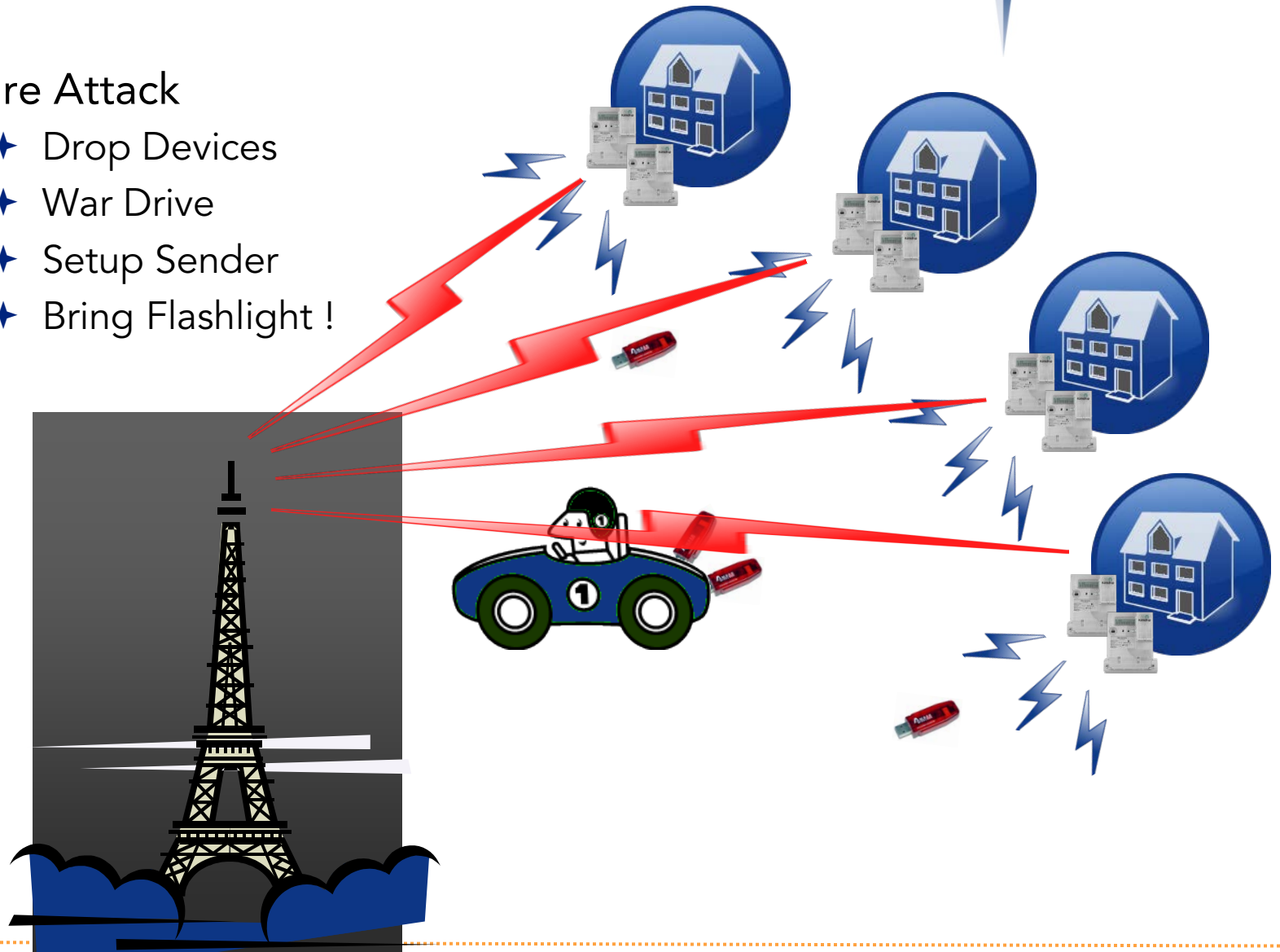
Meter



# Orchestrated Blackouts

## Prepare Attack

- ◆ Drop Devices
- ◆ War Drive
- ◆ Setup Sender
- ◆ Bring Flashlight !





## Conclusion

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## General Issues

- ✦ Key size 64 bits
- ✦ Zero consumption detection
- ✦ Disclosure of consumption values
- ✦ Plaintext errors and alarms
- ✦ Information Disclosure
- ✦ Man-in-the-middle in routed environments
- ✦ Key disclosure



## Energy Fraud

- ✦ Manipulation of consumption value

## Orchestrated Blackouts

- ✦ Manipulation of valve and breaker open/close commands



## Counter Measures

- ✦ Efforts of the OMS Group and the German Federal Office for Information Security (BSI Germany)
  - ✦ Integrity-preserving authentication and fragmentation layer (AFL),
  - ✦ Additional encryption mode relying on AES-128 in CBC mode using ephemeral keys
  - ✦ TLS 1.2 support for wM-Bus
  - ✦ Published on X-Mas 2012
- ✦ Looks promising, no independent public analysis so far



**Battery pack empty.**



**Presentation (temporarily available from scambus git repo)**

[http://www.csnc.ch/misc/files/2013/energy\\_fraud\\_and\\_blackouts.pdf](http://www.csnc.ch/misc/files/2013/energy_fraud_and_blackouts.pdf)

**Whitepaper (temporarily available from scambus git repo)**

[http://www.csnc.ch/misc/files/2013/wmbus\\_security\\_whitepaper.pdf](http://www.csnc.ch/misc/files/2013/wmbus_security_whitepaper.pdf)

**Sniffer & MUC (credits [lukas@statuscode.ch](mailto:lukas@statuscode.ch))**

<https://github.com/CBrunsch/WMBus-Sniffer-MUC>

**Python Sniffer „Scambus“**

<https://github.com/CBrunsch/scambus>

**GNU Radio wM-Bus (credits [neundorf@kde.org](mailto:neundorf@kde.org))**

<https://github.com/oWCTejLVIFyNztcBnOoh/gr-wmbus>

**Cliparts**

<http://openclipart.org>