The Hitchhiker's Guide to Choosing the Compression Algorithm for your Smart Meter Data

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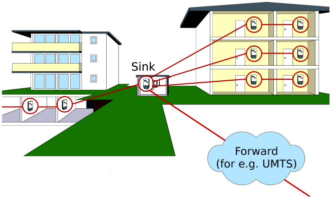
Motivation

- Emerging renewable energy resources
- Grids to be relieved by tariffs for the current supply
- Smart Metering helps the customer
    - Shifting tasks to times with cheaper tariffs
    - Identifying heavy electricity consumers
- Meter data needs to be transmitted, but
    - Bad connectivity for GSM/UMTS in cellars
    - Powerline communication is not available in all areas
- Wireless mesh network
- Hop-to-Hop data transport



Motivation

- Pro:
  - Wireless sensor nodes are cheap
- Contra:
  - Low Bandwidth
  - Bottleneck near Sink
- Reducing network load allows more nodes in network
- Data formats are regulated and mandatory

$\Rightarrow$ Lossless data compression is needed

Smart Meter Data

ASCII-coded (EN-62056-21)

```
F.F(00000000)
0.0.0(00617827)
0.0.1(00000000)
0.9.2(1070813)
1.8.1(00000247*kWh)
1.8.1*04(00000172*kWh)
1.8.1*03(00000103*kWh)
C.51.6*03(0000000000000)
C.51.7(00000000)
C.77.2(0A78422F69654D2D4952481FBF16)
C.86.0(20001010)
31.25(0.008*A)
51.25(0.009*A)
71.25(0.045*A)
32.25(0.66*V)
52.25(0.57*V)
72.25(225.04*V)
1.35.0.01(0.000*kW)
P.01(0080213003000)(00000000)(15)(1)(1.5)(kW)
(00.00)
(00.02)
(00.01)
(02.00)
(00.01)
```

Motivation

- Trade-off: Compression gain $\Leftrightarrow$ Hardware requirements
- Sensor nodes have limited hardware resources
  (RAM, ROM, speed)
- Modern algorithms concentrate on compression gain

Question:

Which compression algorithm gives best results for the recorded data by using as few resources as possible?

What we did:

- Improve compression algorithms for wireless sensor nodes
- Analyze the strengths and weaknesses

Agenda

1. Introduction
2. Compression Algorithms
3. Evaluation
4. Conclusion

Compression Types

- **Entropy Coding:** ▷ More
  Use variable Bit-length codes for symbols, depending on their probabilities. e.g.: Huffman-, Arithmetic-, Range-Encoding
- **Wordbook Compression:** ▷ More
  Recognize repetitions of strings and use references to encode them. e.g.: LZ77, LZ78
- **Block-sorting:** ▷ More
  Rearrange the symbols in a way that they are easier to compress afterwards. e.g.: Burrows-Wheeler-Transformation, Move-To-Front

Reference Compression Algorithms

- Lempel Ziv Storer Szymanski (LZSS)
  Dictionary compression
- Lempel Ziv Welch (LZW)
  Dictionary compression (patent expired, used in GIF)
- DEFLATE (ZLIB, GZIP)
  Dictionary compression with Huffman Encoding (used in HTTP, PDF, ...)
- BZIP2
  Block sorting with Range-encoding
- Lempel Ziv Markov Chain Algorithm (LZMA)
  Dictionary compression with Reference History and subsequent Range-encoding

Entropy-based Compression

Adaptive Trimmed Huffman Coding (ATH)

▷ More

- Developed for energy-constrained wireless sensor nodes
- Adaptive Entropy Coding Scheme
- Huffman tree is trimmed to reduce memory consumption
- Prefix determines the encoding of next symbol

Adaptive Markov Chain Huffman Coding (AMCH)

▷ More

- Uses probabilities of successive symbols
- Each symbol has Huffman tree of following symbols
- Trees are built during compression
- Each tree has Escape symbol for not yet encountered (NYE) symbols

Wordbook-based Compression

tiny Lempel Ziv Markov Chain Algorithm (tLZMA)

- Adaption of the LZMA Scheme
- History window constrained to 128 Byte
- No Range-encoding step

Lempel Ziv Markov Chain Huffman Coding (LZMH)

- Combination of tLZMA and ATH
- Dictionary compression with 128 Byte History
- Compression of symbols with ATH method

Evaluation Methodology

Data

- 3 500 ASCII-coded (EN-62056-21) datasets
  - From real smart meter installation
  - Size range from 76 to 3 100 Byte
- 95 power consumption measures of household devices
  - Sampled about once per second
  - Data in binary format
  - Sizes between 18.8 and 171.0 KByte

Methodology and Metrics

- All Methods implemented in C, no use of heap memory
  ZLIB, BZ2 and LZMA implementations use heap memory
- Compression rate benchmarked on a desktop PC
- Compression rate $= 1 - \frac{\textit{compressed data size}}{\textit{uncompressed data size}}$
- Processing time benchmarked on ATmega 1281 (8 kB RAM, 7.37 MHz)
- Processing time over size $= \frac{\textit{consumed time}}{\textit{uncompressed data size}}$

Memory Consumption

Algorithm	ROM (Byte)	RAM (Byte)	
		static	stack
LZSS	544	129	19
LZW	550	12 416	16
ZLIB	27 960	2 690	ca. $>$ 1 000*
BZ2	28 332	1 564	ca. $>$ 100 000*
LZMA	34 442	110	ca. $>$ 6 000 000*
ATH	592	170	15
AMCH	1 680	1 820	21
tLZMA	992	133	27
LZMH	1 428	378	29

(*) Heap Memory

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(*) Heap Memory

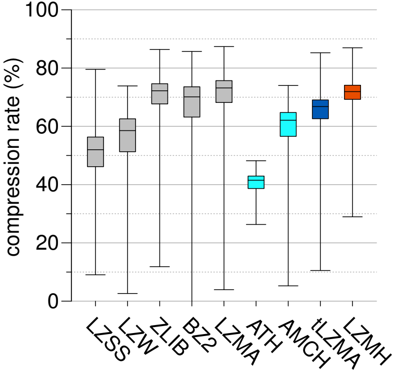
ZLIB, BZ2, LZMA and LZW use too much memory

⇒ can not be tested on

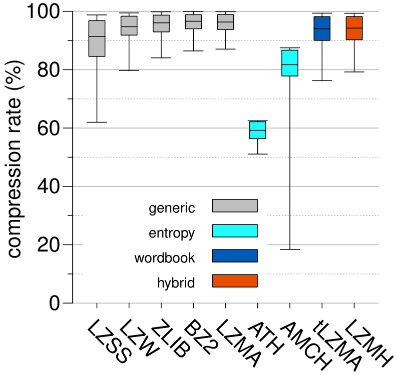
ATmega 1281

Compression Rate

ASCII encoded smart meter datasets



binary encoded daily device reports

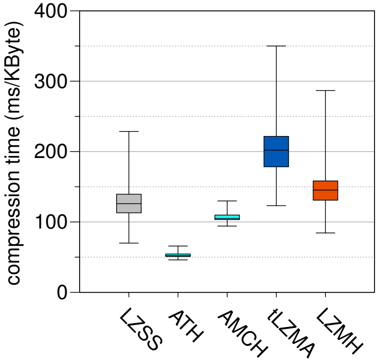


- LZMH achieves compression rates comparable to ZLIB, BZ2 and LZMA
- ATH performs good for small, but poor for bigger datasets

▷ Histogram

Processing Time

- ATH is the fastest
- ATH and AMCH are mostly unaffected by the dataset
- Other methods depend on the compressability of the datasets



▷ Histogram

Selection Guidelines

	LZSS	ATH	AMCH	tLZMA	LZMH
ROM	++	++	o	+	o
RAM	++	++	−−	++	+
Performance	o	++	+	−	o
Compression Gain	−	−−	o	+	++

Scenarios:

- Very limited resources
  - Focus on performance $\rightarrow$ ATH
  - Focus on compression $\rightarrow$ LZSS
- Limited resources, focus on compression $\rightarrow$ tLZMA
- Moderate resources, best compression $\rightarrow$ LZMH
- Good compression with predictable performance $\rightarrow$ AMCH

Resume

- Lossless data compression to reduce:
  - bandwidth
  - energy consumption
  - transmission costs
- Trade-off between compression gains, time, and resources
- ATH, LZMH, LZSS and tLZMH fulfill the resource constraints
- LZMH gives best compression results with moderate execution times and resources
- ATH is the fastest method, but has lowest compression rates

The Hitchhiker's Guide to Choosing the Compression Algorithm for your Smart Meter Data

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Appendix

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Entropy

- Measure for the average self-information and the information density of a code system
- n: Number of symbols, p_i: Probability of a symbol

  $$H = -\sum_{i=1}^{n} p_i \cdot \log_2 p_i$$
- The entropy is the average number of needed bits to encode one symbol in a message

▷ Back

Move-To-Front Example

Symbol	Sequence	Alphabet
b	1	abcdefghijklmnopqrstuvwxyz
a	1	bacdefghijklmnopqrstuvwxyz
n	13	abcdefghijklmnopqrstuvwxyz
a	1	nabcdefghijklmopqrstuvwxyz
n	1	anbcdefghijklmopqrstuvwxyz
a	1	nabcdefghijklmopqrstuvwxyz

▷ Back

LZSS Example

```
Hello you there, yea you there, yea you there,
Hello!
```

Becomes:

```
Hello you there, yea(5,11)(18,15)(0,5)!
```

The Numbers in brackets determine the offset and length of the previous occurrence of the following string.

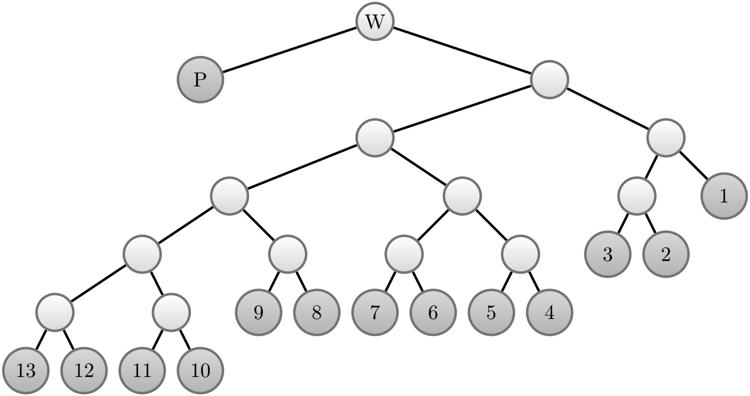
▷ Back

Range-encoding Example

Message: AABA$
Intervals: A: 0 to 0,6 - B: 0,6 to 0,8 - $: 0,8 to 1
A - 0 to 0,6
A - 0 to 0,36
B - 0,216 to 0,288
A - 0,216 to 0,2591
$ - 0,25046 to 0,2591
$\Rightarrow$ 0,251 is the shortest number that lies in the end interval and thereby encodes the message AABA$.

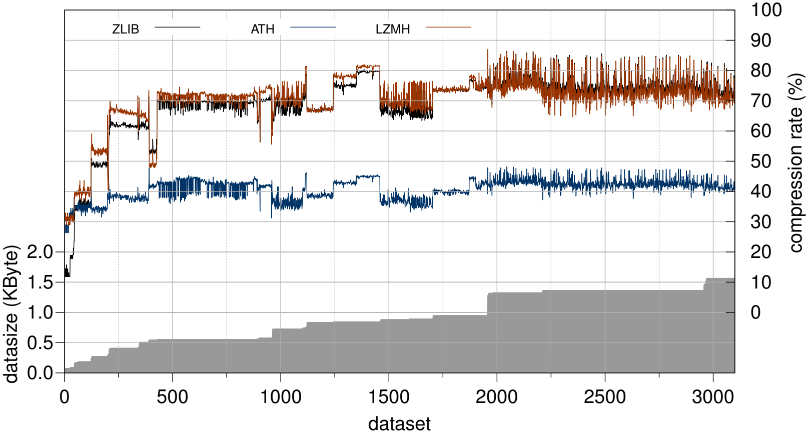
▷ Back

The used ATH tree



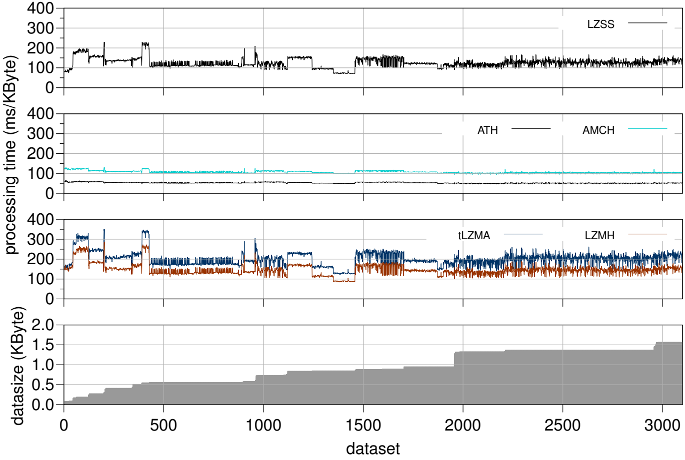
▷ Back

Histogram



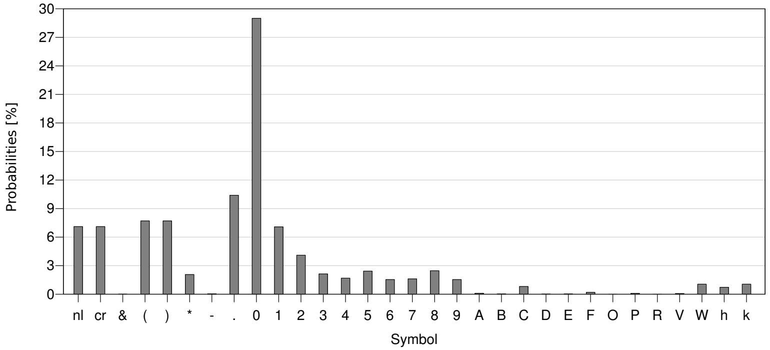
▷ Back

Histogram of Times

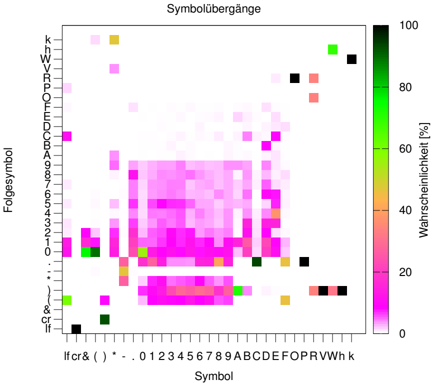


▷ Back

Symbol Histogram



Symbol-transition Heatmap



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