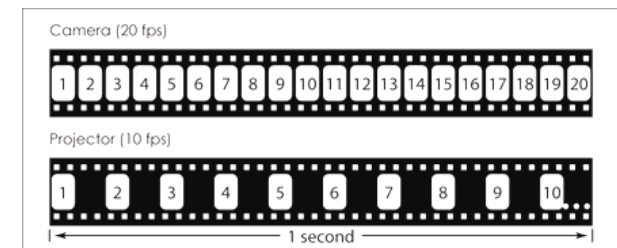




Coarse-grained cycle-accurate method (analytical accounting of electricity)

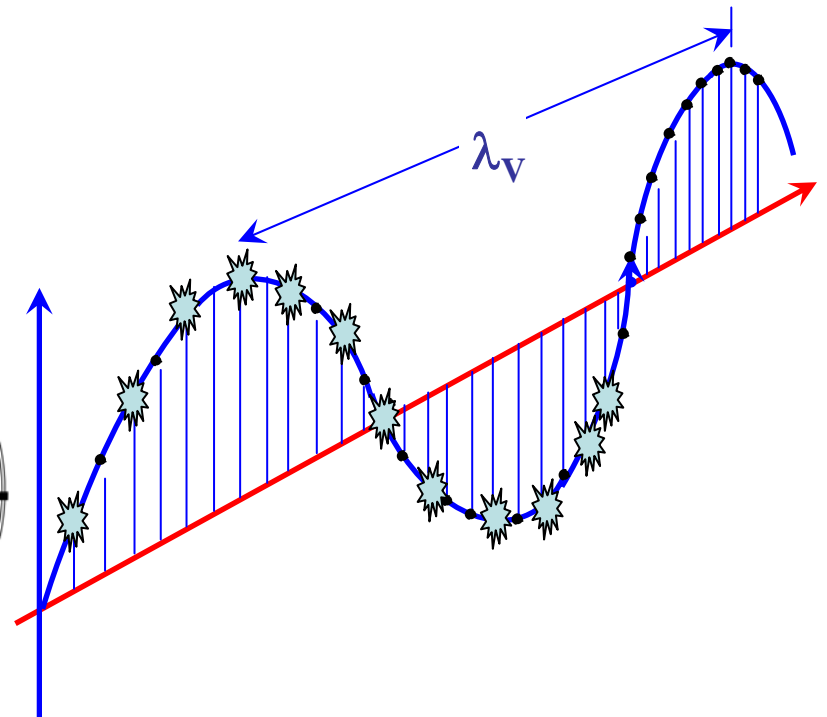
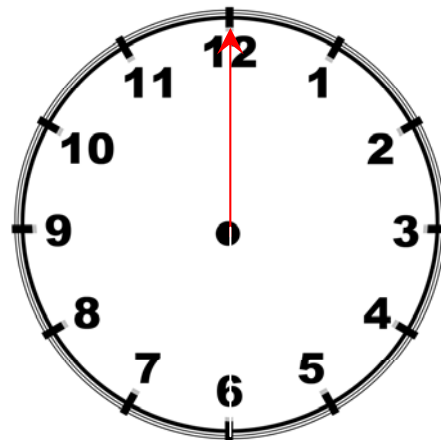
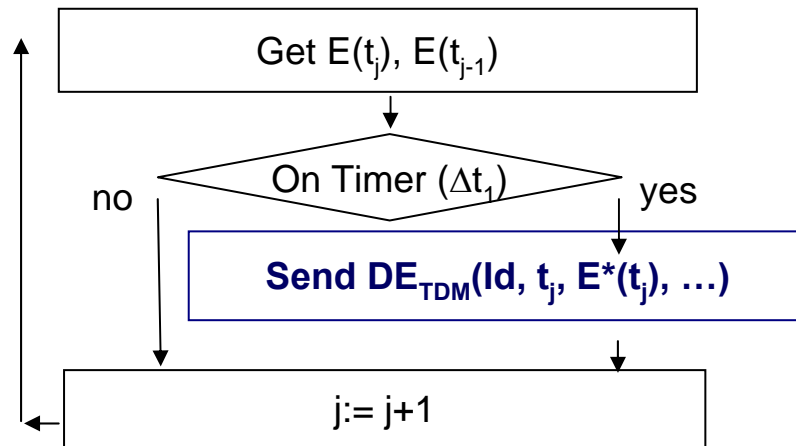
Mikhail Simonov, Ph.D.
simonov@ismb.it



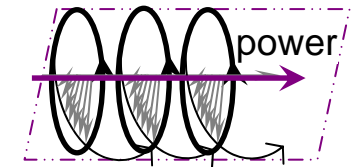
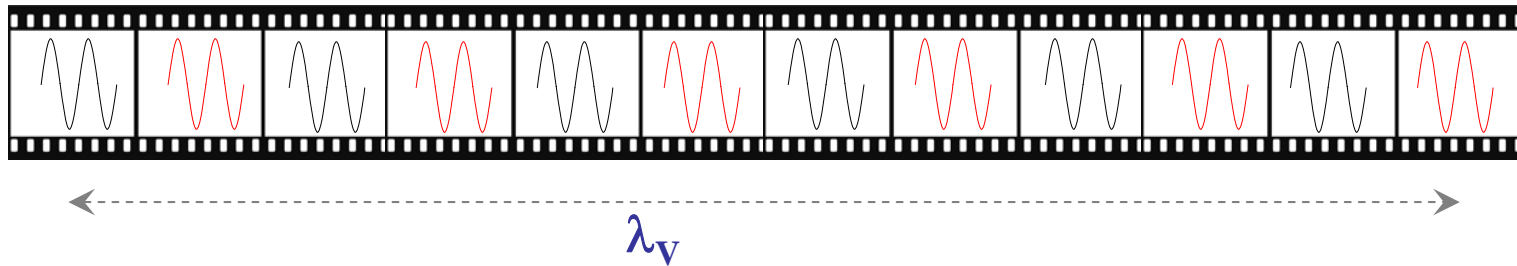
Inside **timer-driven meters**, the waveforms of electricity are observed *by using frequent time sampling (32 kHz = 640 samples per AC cycle; every 31 μ s).*

Our fine-grained measurements (50 Hz) are cycle-precise (every 20 ms).

32,000 fps



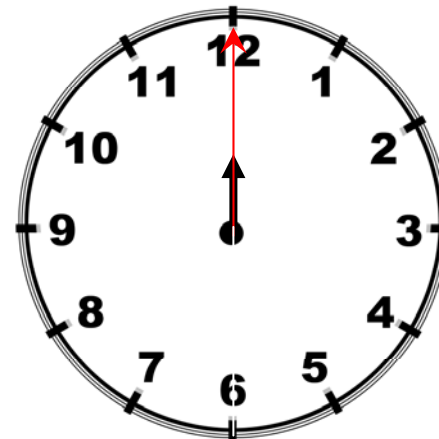
Fine-grained **energy-per-interval** integrals are computed based on the above samples of **voltages** and **currents** taken in the **local discrete time**.
 Fine-grained data (50 packets per second) cannot be shared network-wide.



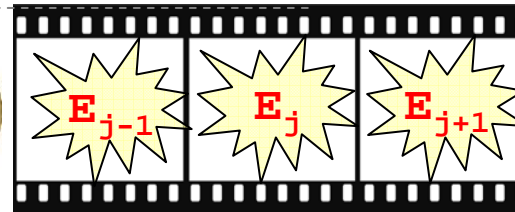
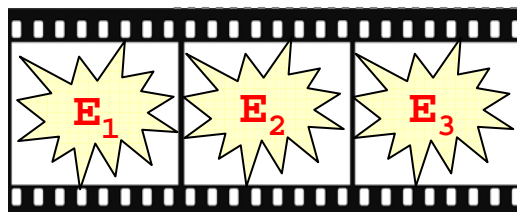
32,000 fps

```

LOOP
  GET N SAMPLES OF  $V(t_k)$  and  $I(t_k)$ ;
   $E_{\text{cycle}} = 0$ ;
  FOR  $j=0$  TO  $N$ 
    COMPUTE  $E_j = V_j * I_j$ ;
    COMPUTE  $E_{\text{cycle}} = E_{\text{cycle}} + E_j$ ;
  UNTIL TRUE;
  
```

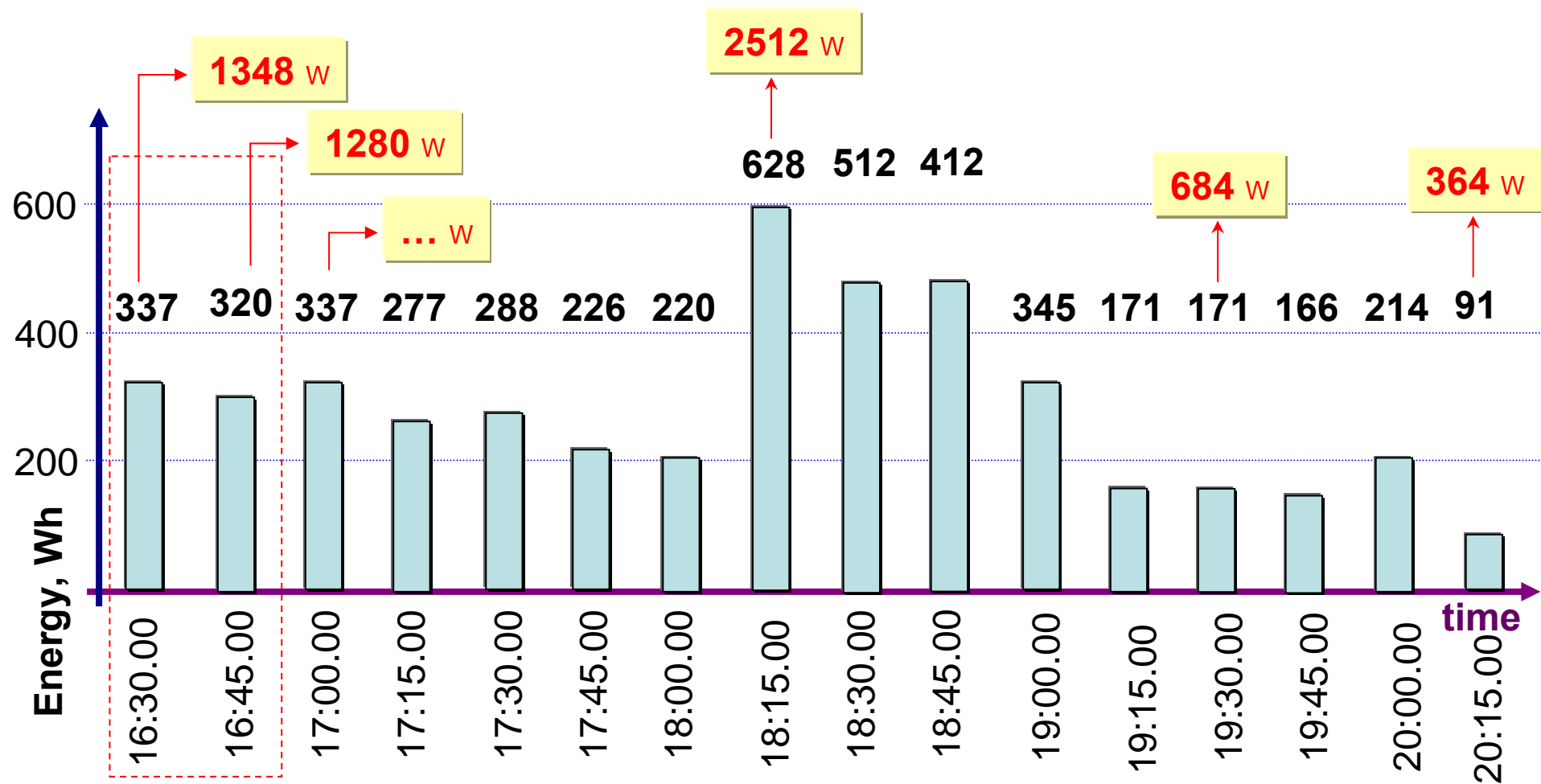


50 (60) fps



To exchange data network-wide, the measurements become coarse-grained.

Timer-driven legacy metering sends **few** (48 - 144 daily datasets) averaged measurements only every 5, 10, 15, or 30 minutes.



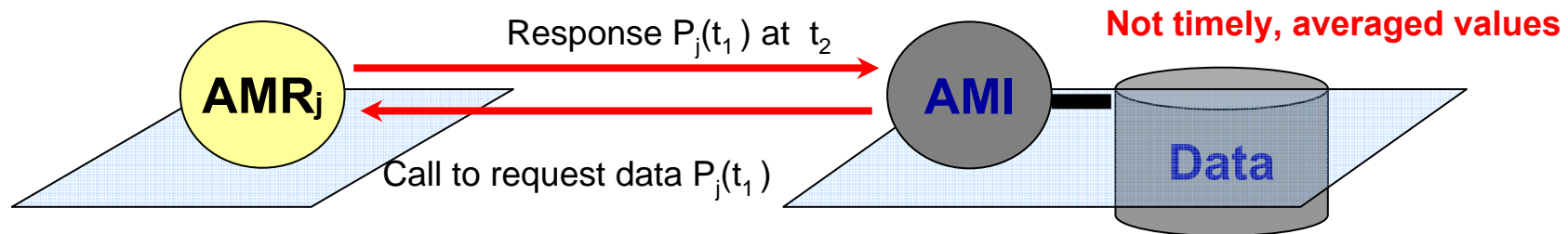
Averaged pseudo-measurements of *energy-per-interval* **can be derived** every 15'

Averaged power is computed as $P^* = dE / 900 * 3600$

Timer-driven legacy metering uses polling to get the data.

In TDM scheme, each meter **is asked** to provide the metering data.

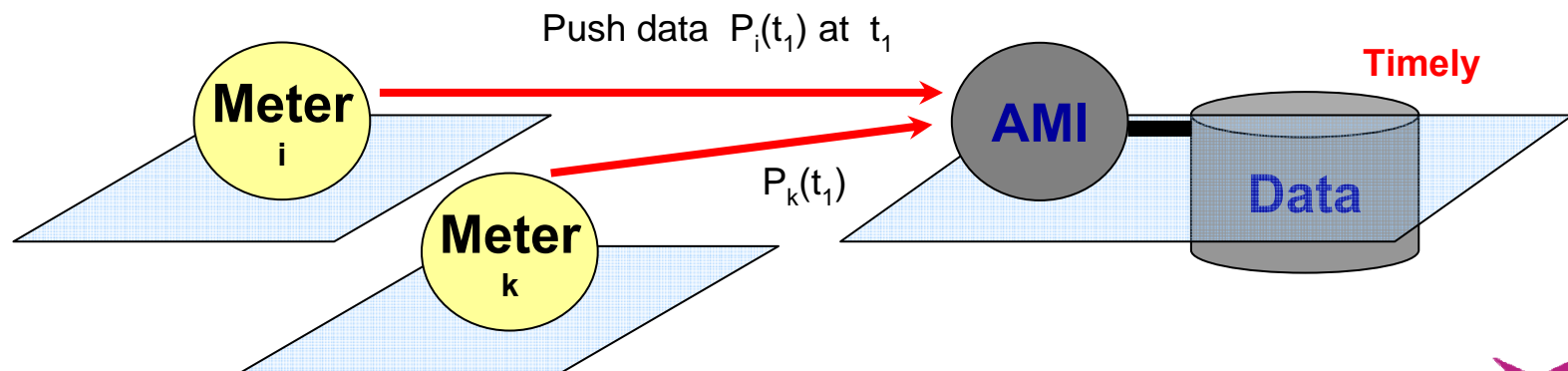
Data traffic (100%) = requests-for-data (50%) + replies (50%).



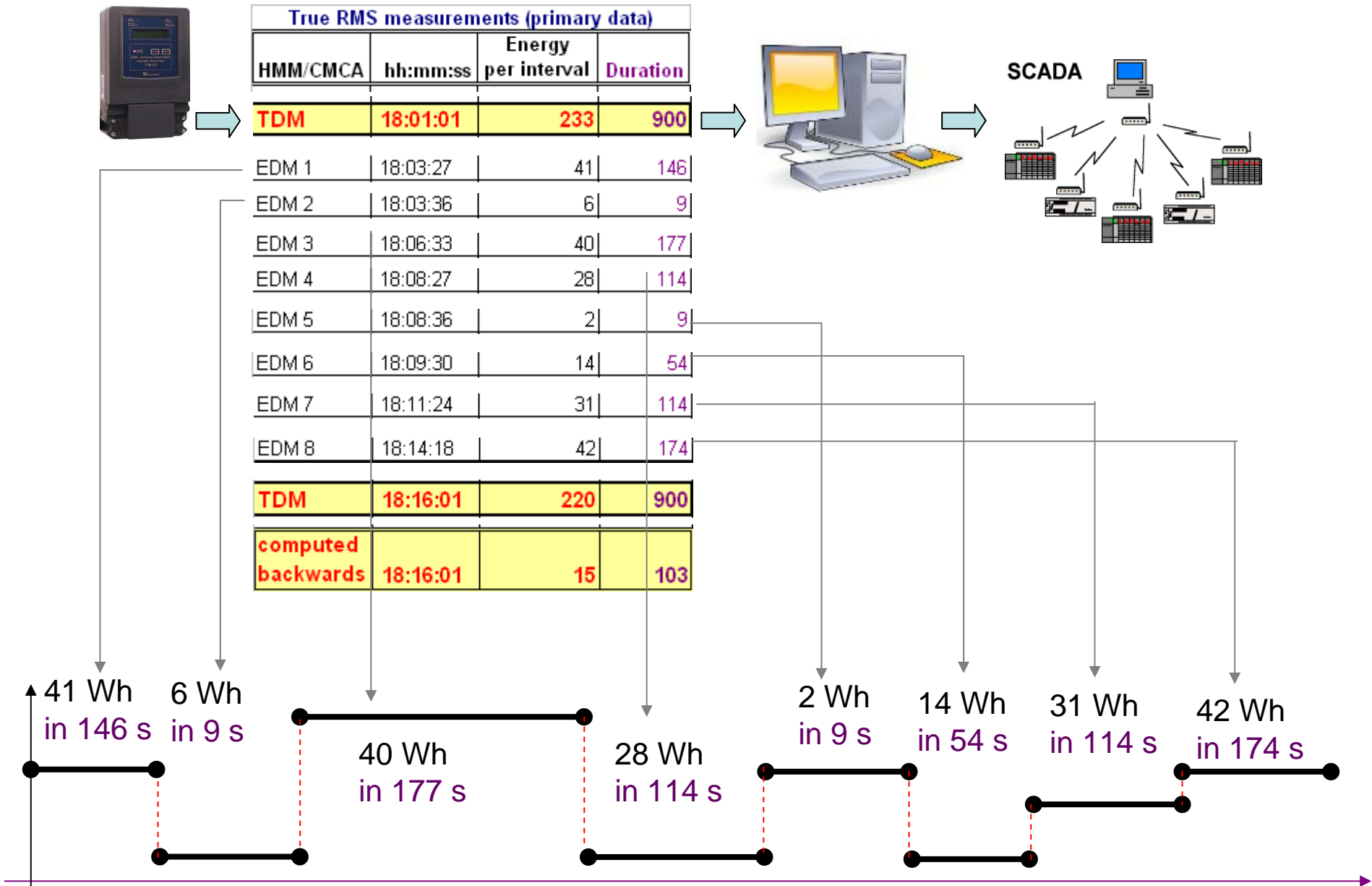
In **event-driven approach**, meters push data, while the AMI host listens.

Meters **are not asked** (50% of the data traffic) to provide metering data.

We **halved the data traffic**.



In event-driven approach, meters send **events** in real-time, **record-by-record**.
 The **chain of process-oriented segments** (chunks) appears.

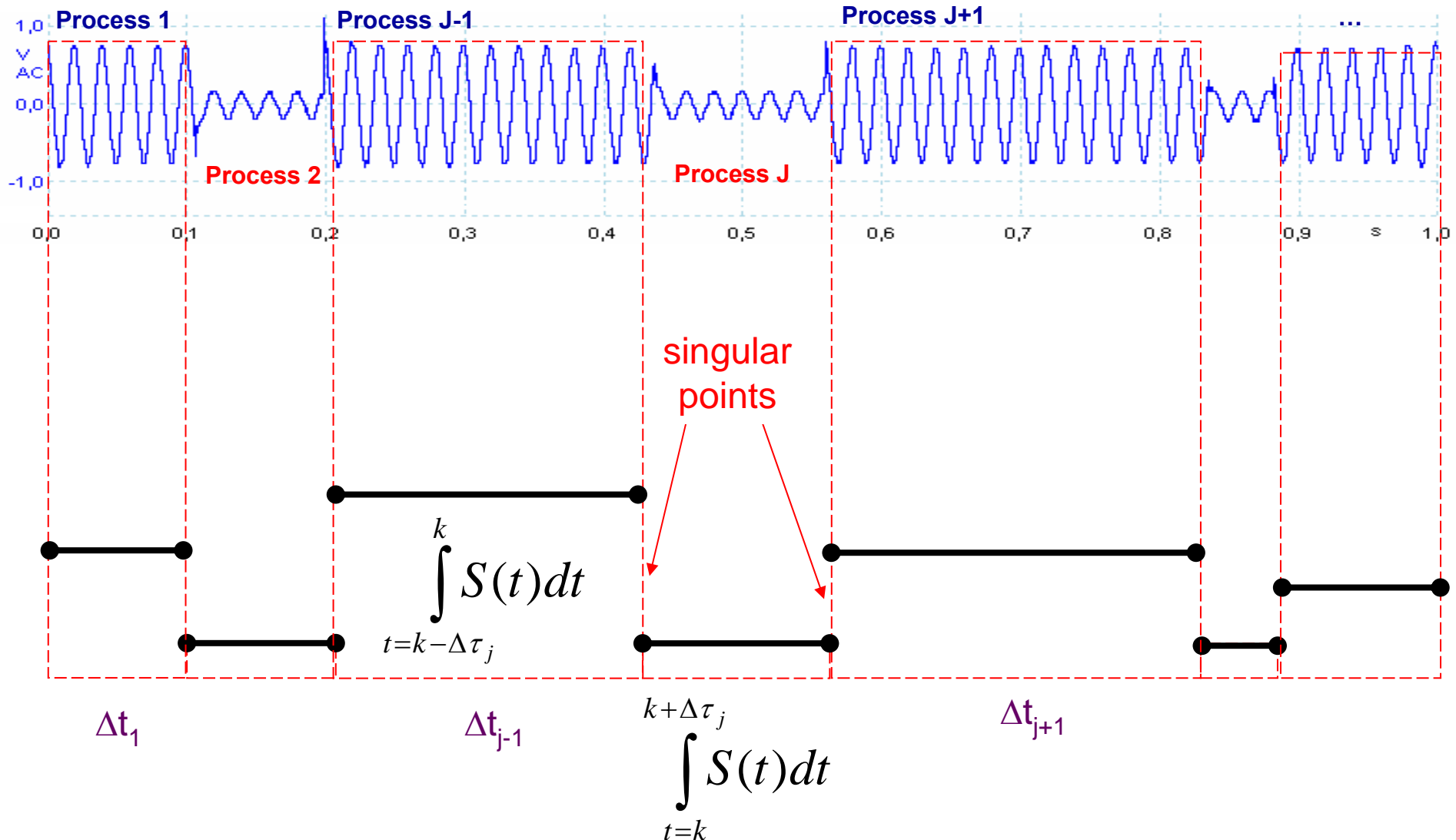


Steady **power** (periods) imply **duplicates** of the **energy-per-interval**.

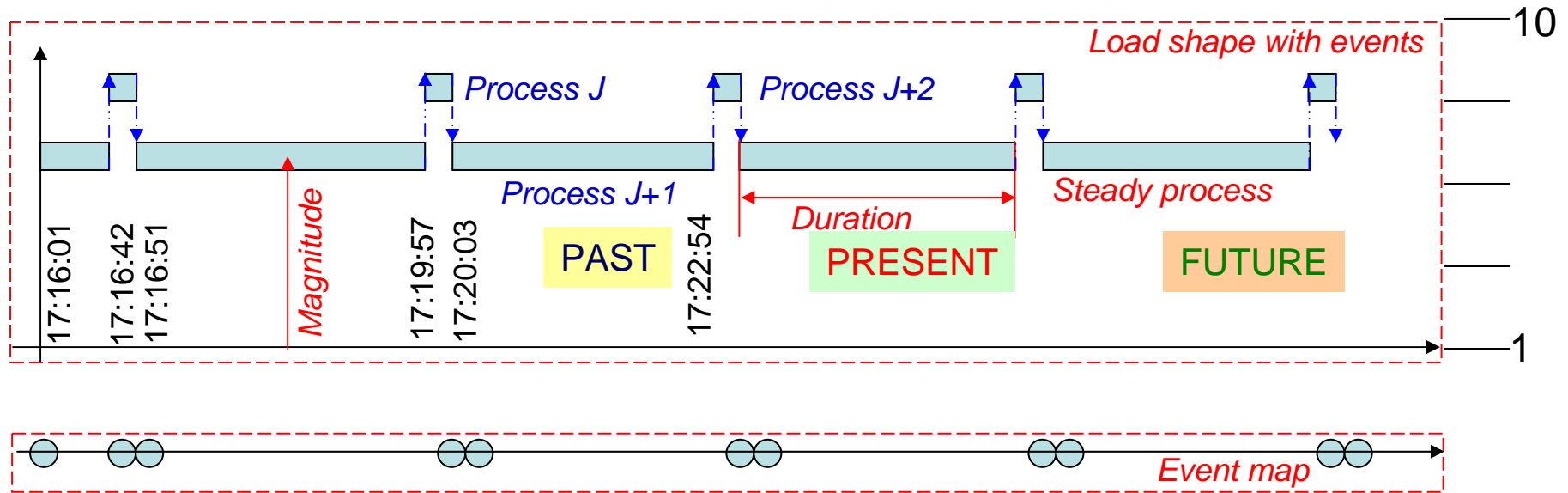
Geometric integration (change→point) originates a polygonal line.

The time is now partitioned in finite segments flowing at **non-uniform rates**.

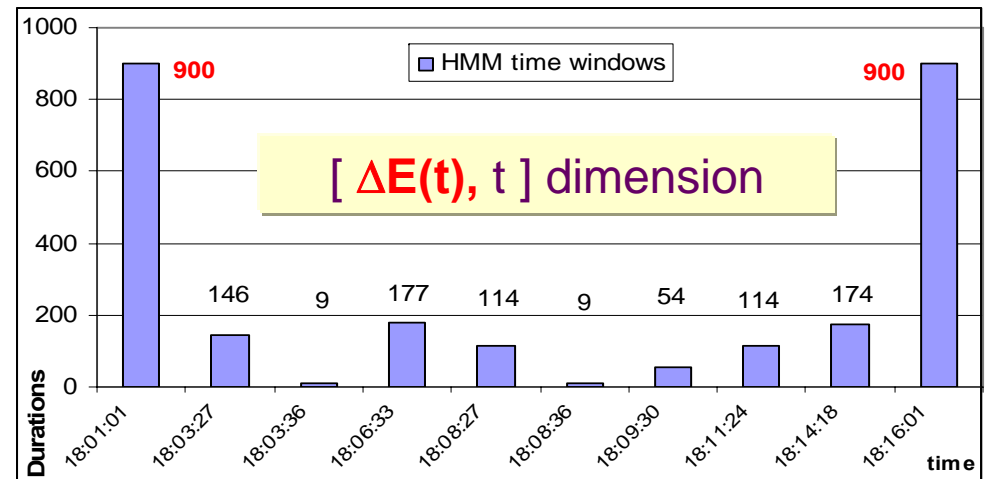
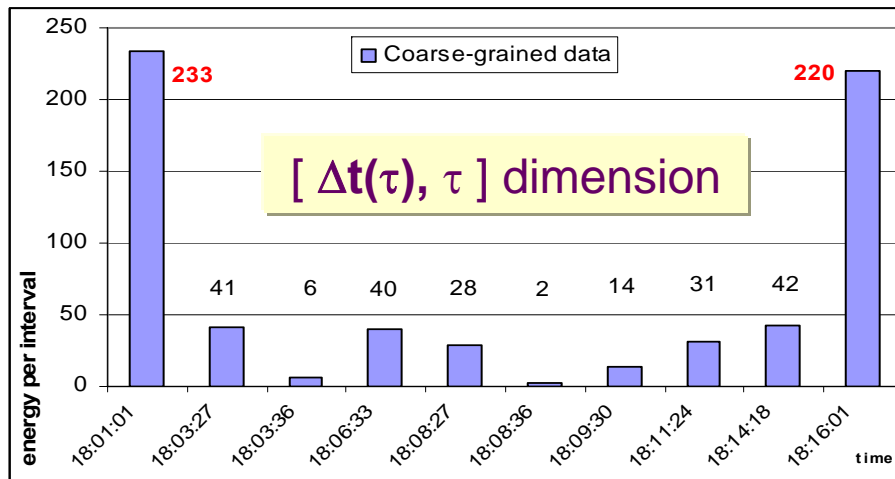
Each change → a singularity → derivative of energy does not exist.



As a result, we got process-oriented knowledge about real-life happenings ... and the map of events (in the sample space).

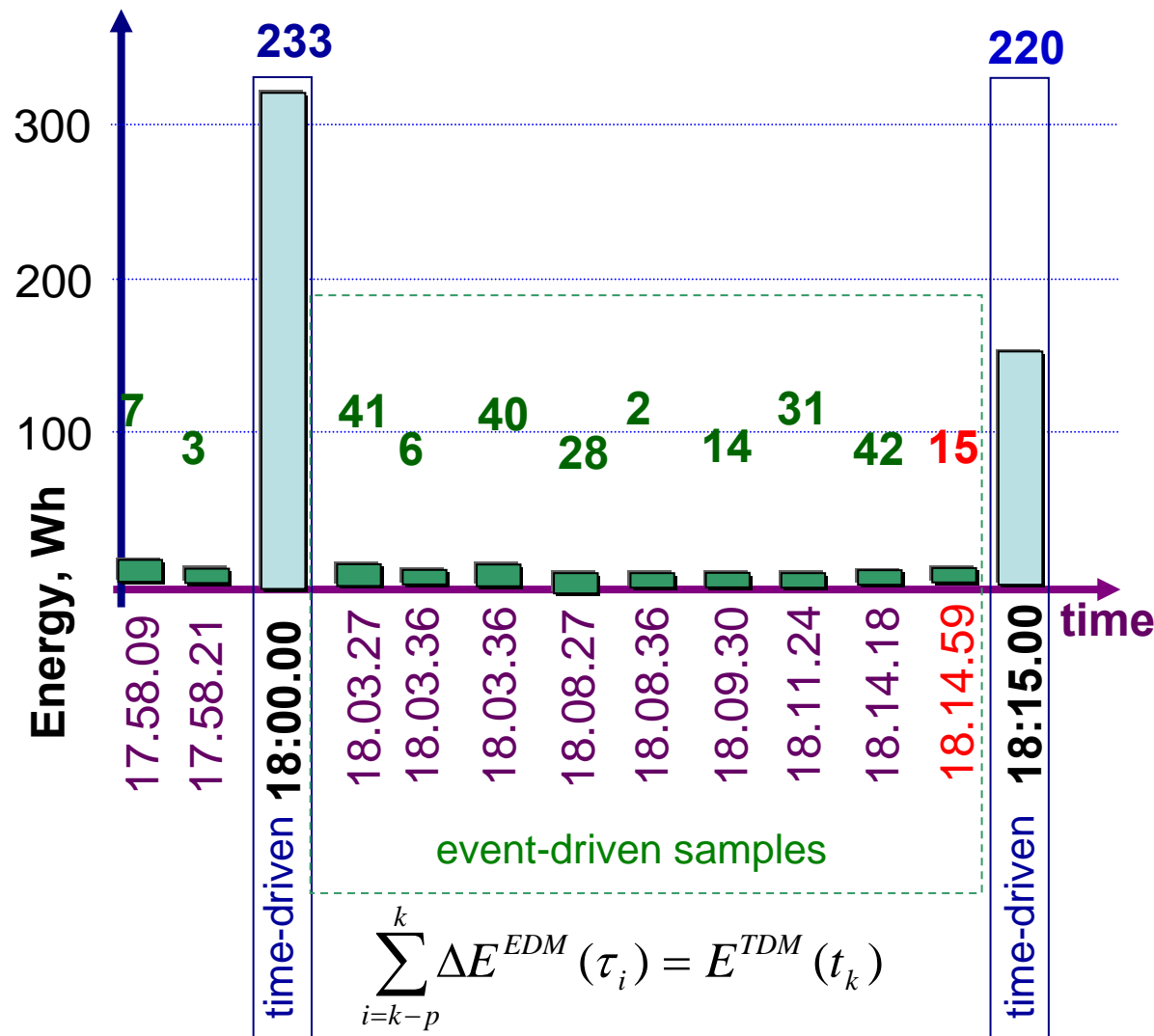


We got 2 bi-dimensional data sets (e.g. one 4-D data object) to visualize.



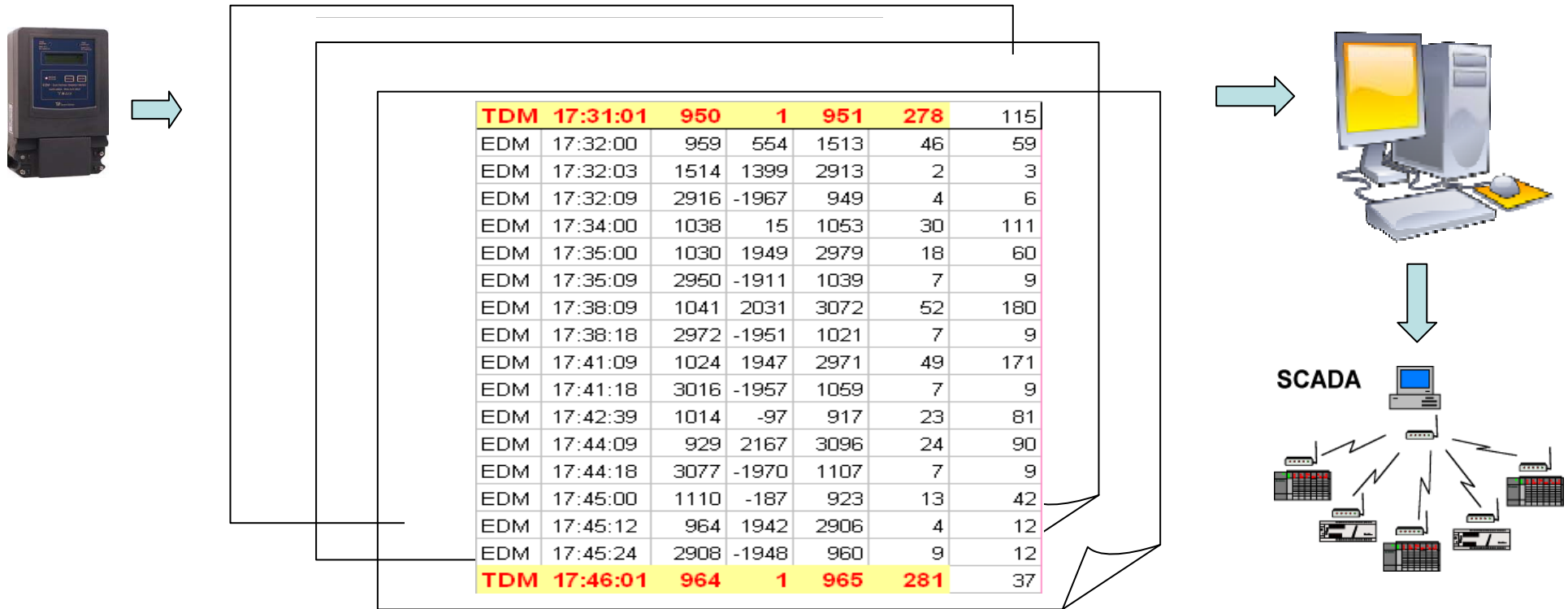
Infrequent averaged timer-driven values are used as **reference frames** (time windows)
 True rms measurements of **energy-per-interval** come upon events in real time
 Coarse-grained method delivers **process knowledge** (timestamp + magnitudes + duration)
 It lets compute important values: the **next energy level** and **power-per-interval** $P^* = \Delta E / \Delta t$

True RMS measurements (primary data)			
HMM/CMCA	hh:mm:ss	Energy per interval	Duration
TDM	18:01:01	233	900
EDM 1	18:03:27	41	146
EDM 2	18:03:36	6	9
EDM 3	18:06:33	40	177
EDM 4	18:08:27	28	114
EDM 5	18:08:36	2	9
EDM 6	18:09:30	14	54
EDM 7	18:11:24	31	114
EDM 8	18:14:18	42	174
TDM	18:16:01	220	900
computed backwards	18:16:01	15	103

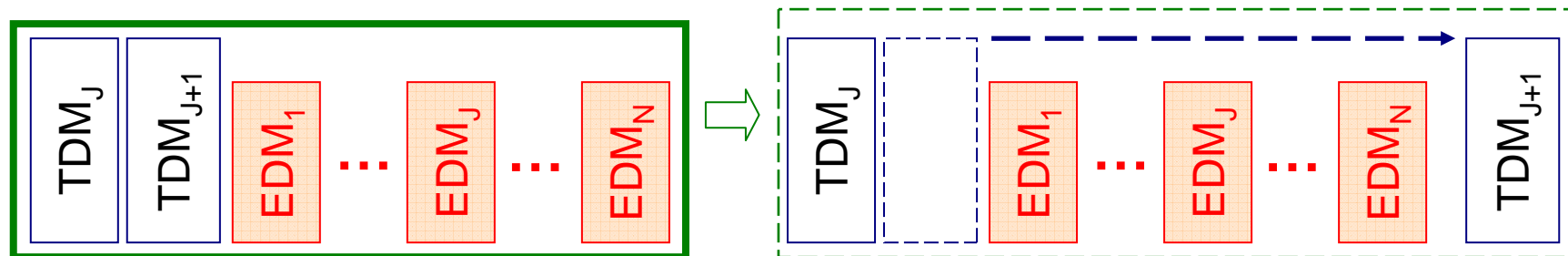


When the real-time horizon is not required, but the analytical data is welcome,
 We send analytical energy **data in batches** only.

This way, it is possible to preserve the compatibility with the Legacy AMI.



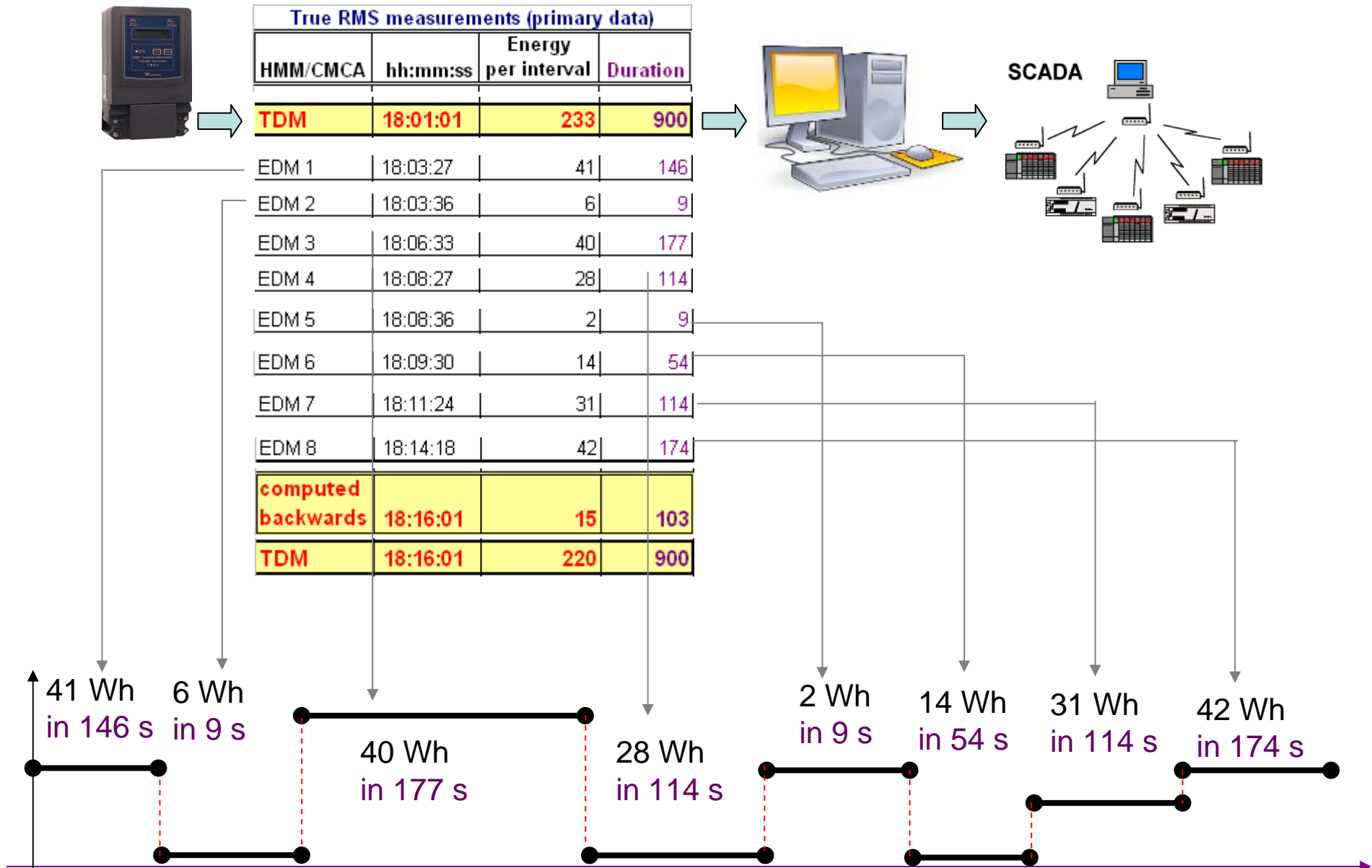
The only need is to re-order frames.



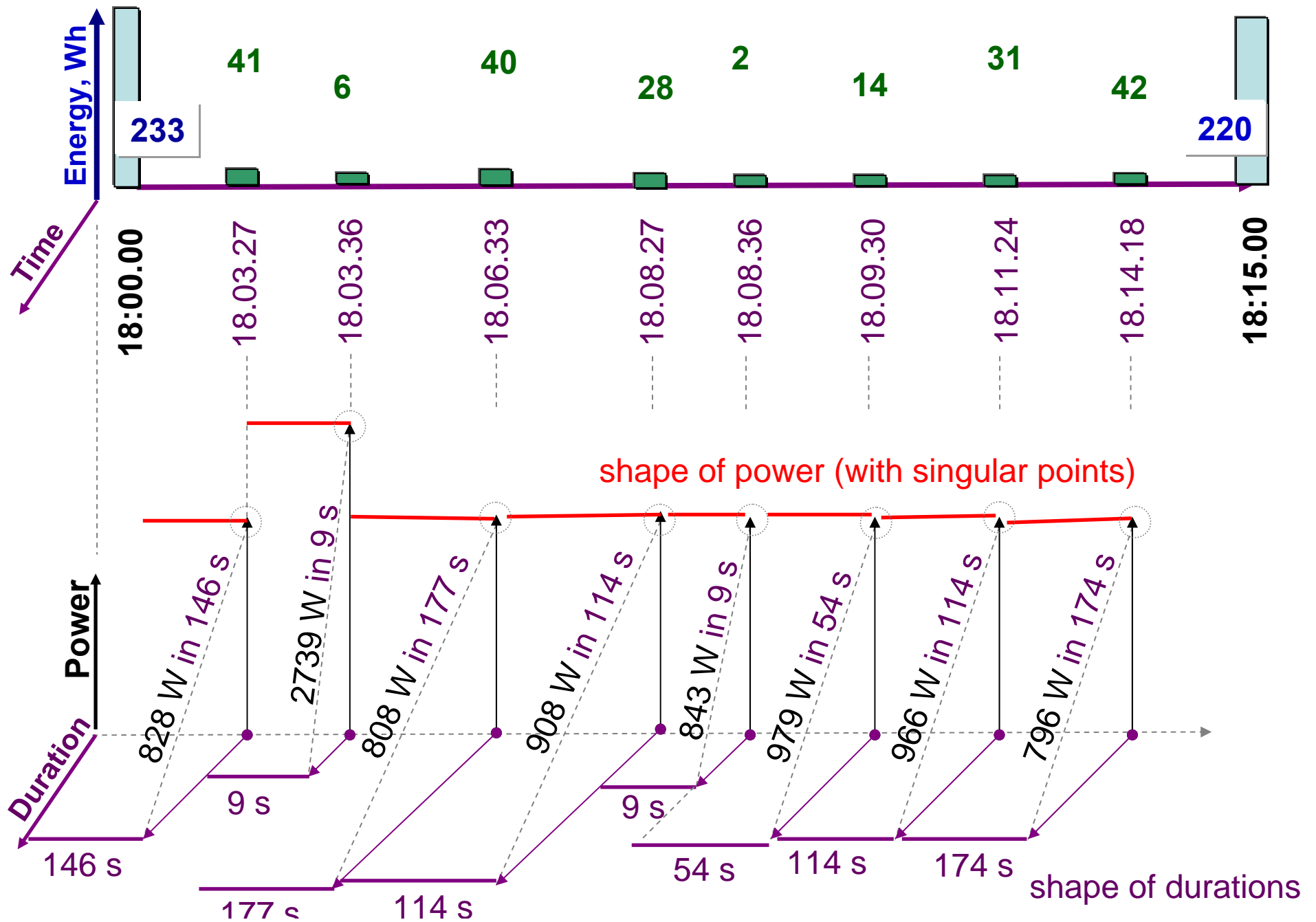
In CMCA approach, meters send **events** in **batches, altogether**

All computations + reasoning could be made in advance by/on CMCA meters

... e.g. CMCA scheme enables ubiquitous computations.



CMCA brings the **process knowledge** (exact shapes of power analytically described).

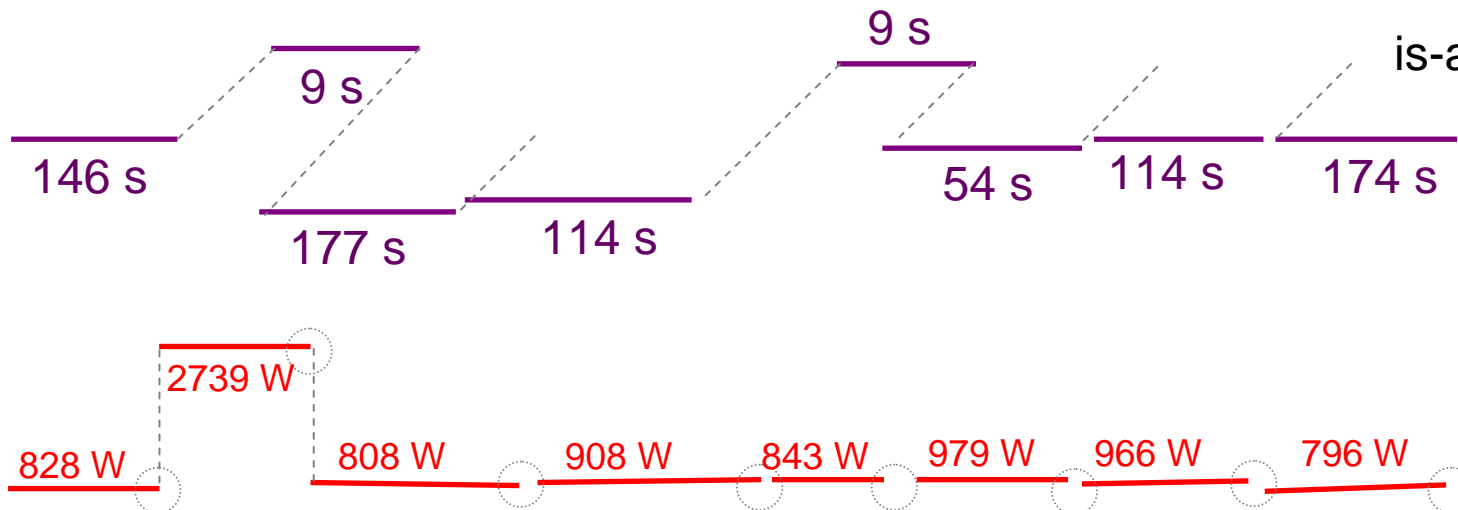


CMCA associates **costs** of energy to real-life **processes** (shown as **polyline**)

CMCA improves the state estimation ($\nabla P_j < P^*$) and forecast $E_{next} = E_{prev} + \Delta E_j$

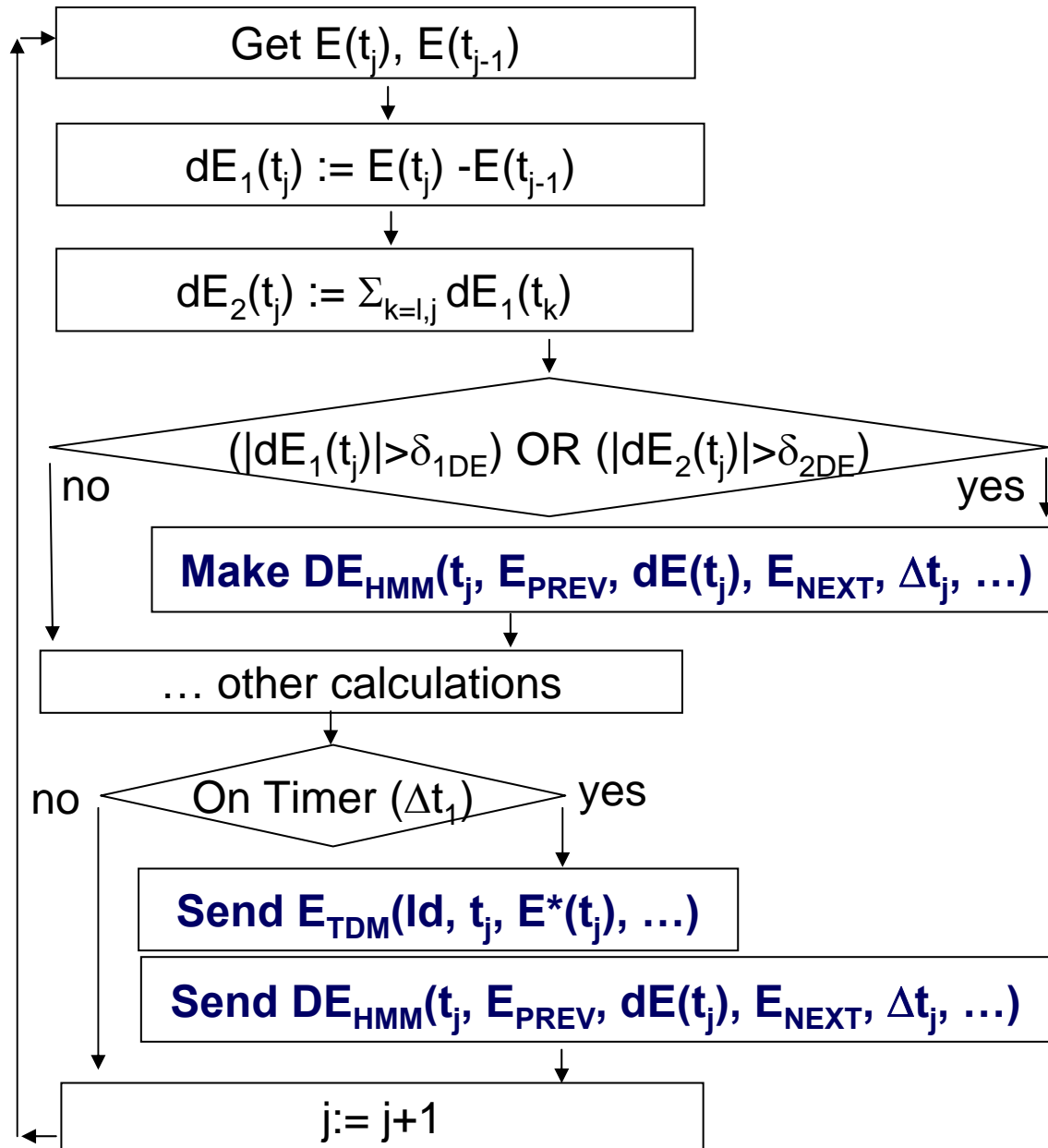
True RMS measurements (primary data)			
HMM/CMCA	hh:mm:ss	Energy per interval	Duration
TDM	18:01:01	233	900
EDM 1	18:03:27	41	146
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EDM 8	18:14:18	42	174
TDM	18:16:01	220	900
computed backwards	18:16:01	15	103

Computed values (derived data)					
Pprev	dP	Pimb	Accumulated energy	Pnext	Nota
814	0	-10	1792	814	6
828	1969	1973	1825,3	2797	6
2739	-1950	-2008	1831,7	789	7
808	120	139	1872	928	6
908	-127	-147	1900,3	781	6
843	45	107	1902,4	888	6
979	11	102	1916	990	6
966	-94	-118	1946,8	872	6
796	-28	-104	1989,1	768	6
763	0	-5	2012	763	6



Real-life process' pattern
 is-a structured object =
 shape of durations
 e.g. pattern
 +
 shape of power(s)
 e.g. pattern

The Coarse-grained Cycle-precise measuring method sends analytical energy **data in batches** only at the same timing as the Legacy timer-driven method.

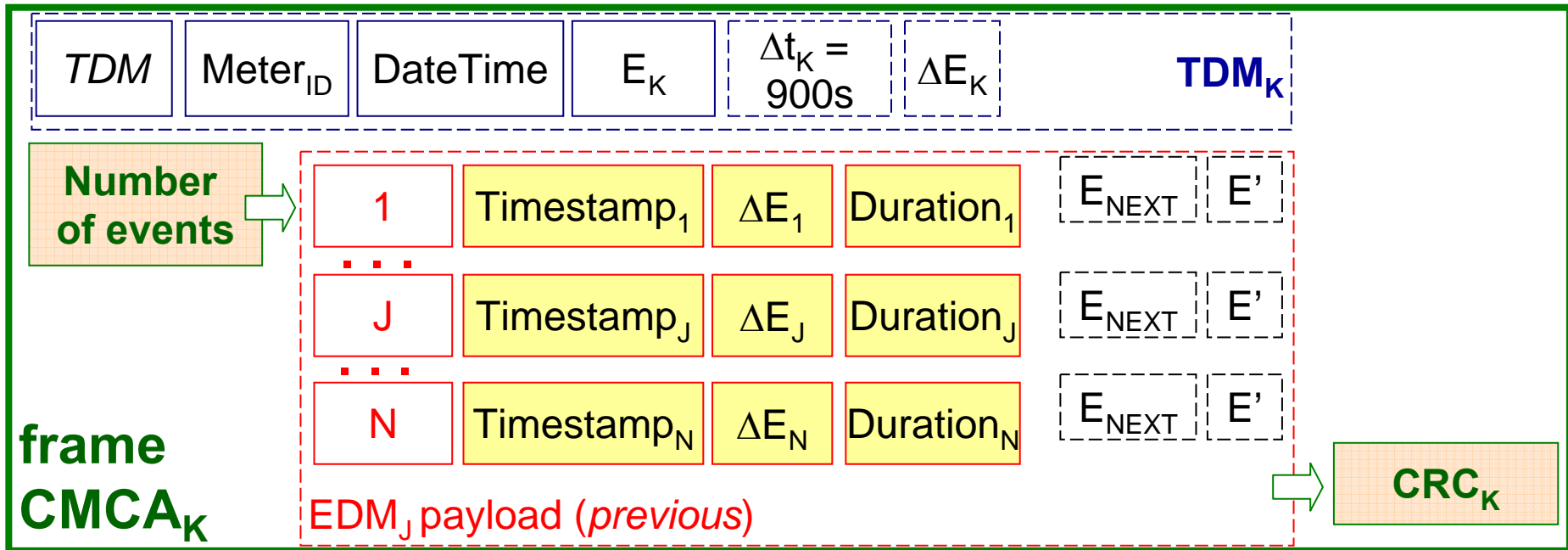


True RMS measurements (primary data)			
HMM/CMCA	hh:mm:ss	Energy per interval	Duration
TDM	18:01:01	233	900
EDM 1	18:03:27	41	146
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EDM 4	18:08:27	28	114
EDM 5	18:08:36	2	9
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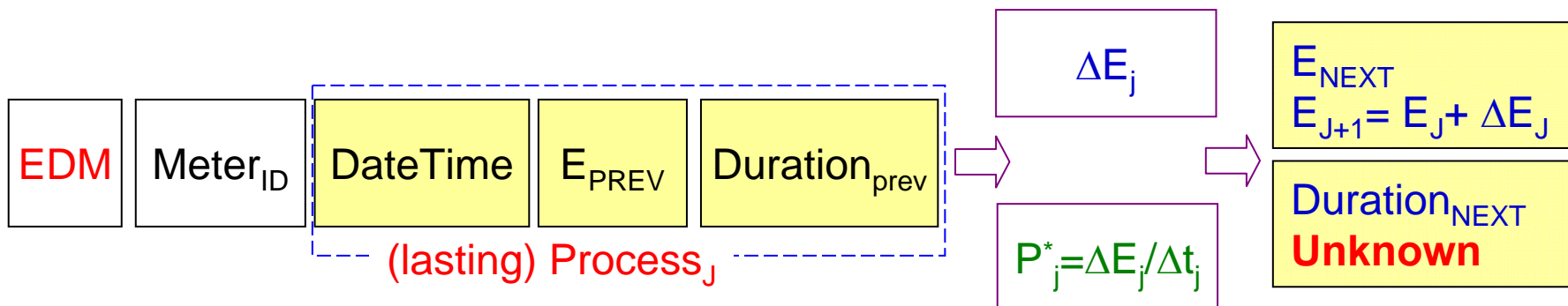
true stateful measurement (locally)

both averaged absolute pseudomeasurement and true stateful measurement (together, delayed)

The data structure of the CMCA method contains a variable-length item



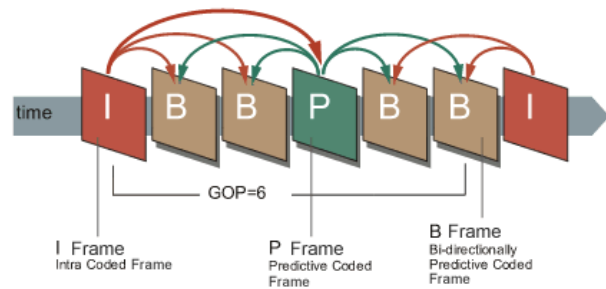
It enables the predictive computations...



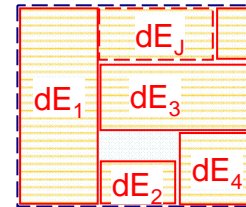
CMCA inherits from MPEG compression: absolute frames coming at regular time-intervals give sliding time-windows (as reference frames).

Packets lost from within the current time-window **are computed** at its end.

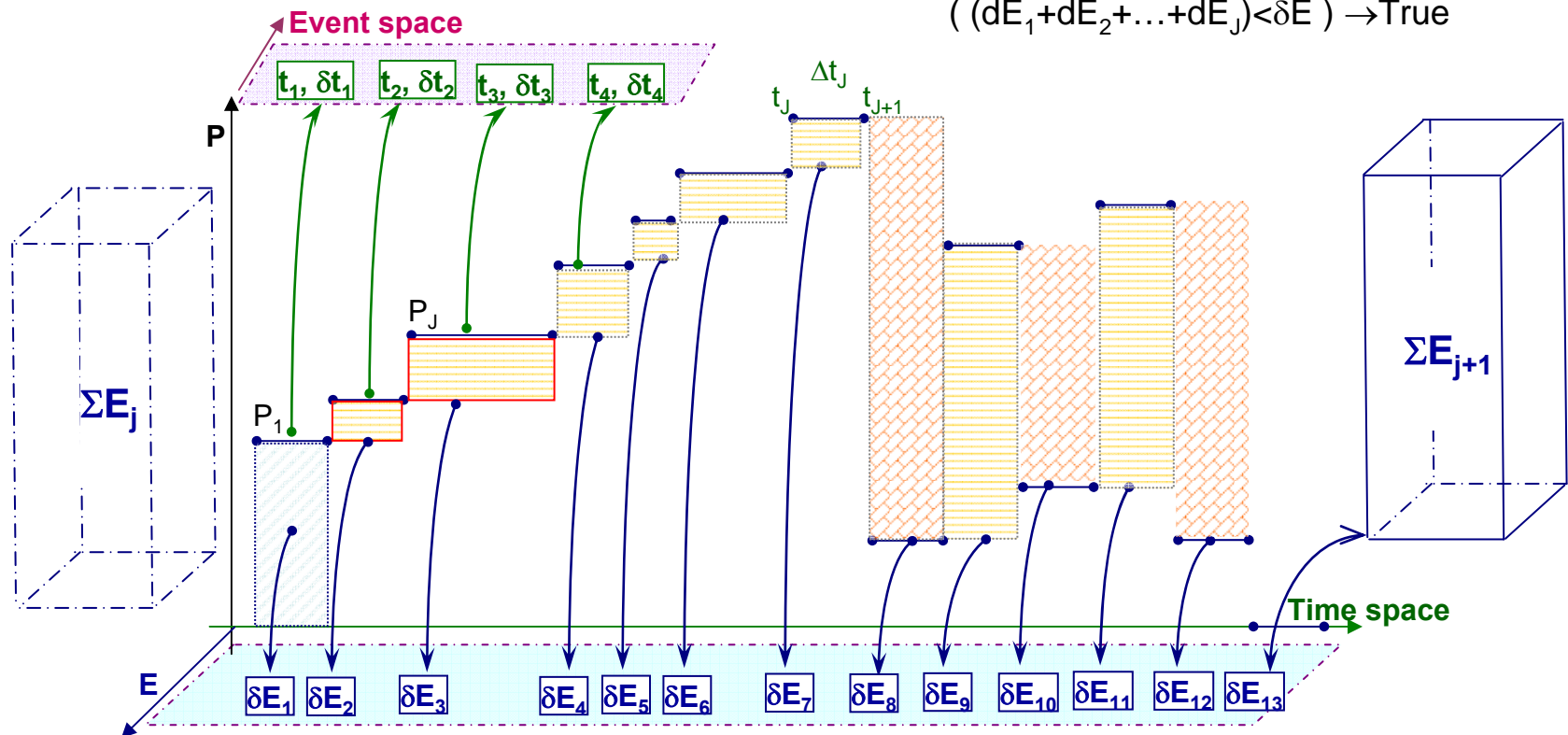
MPEG-2



“accumulated unbalance”



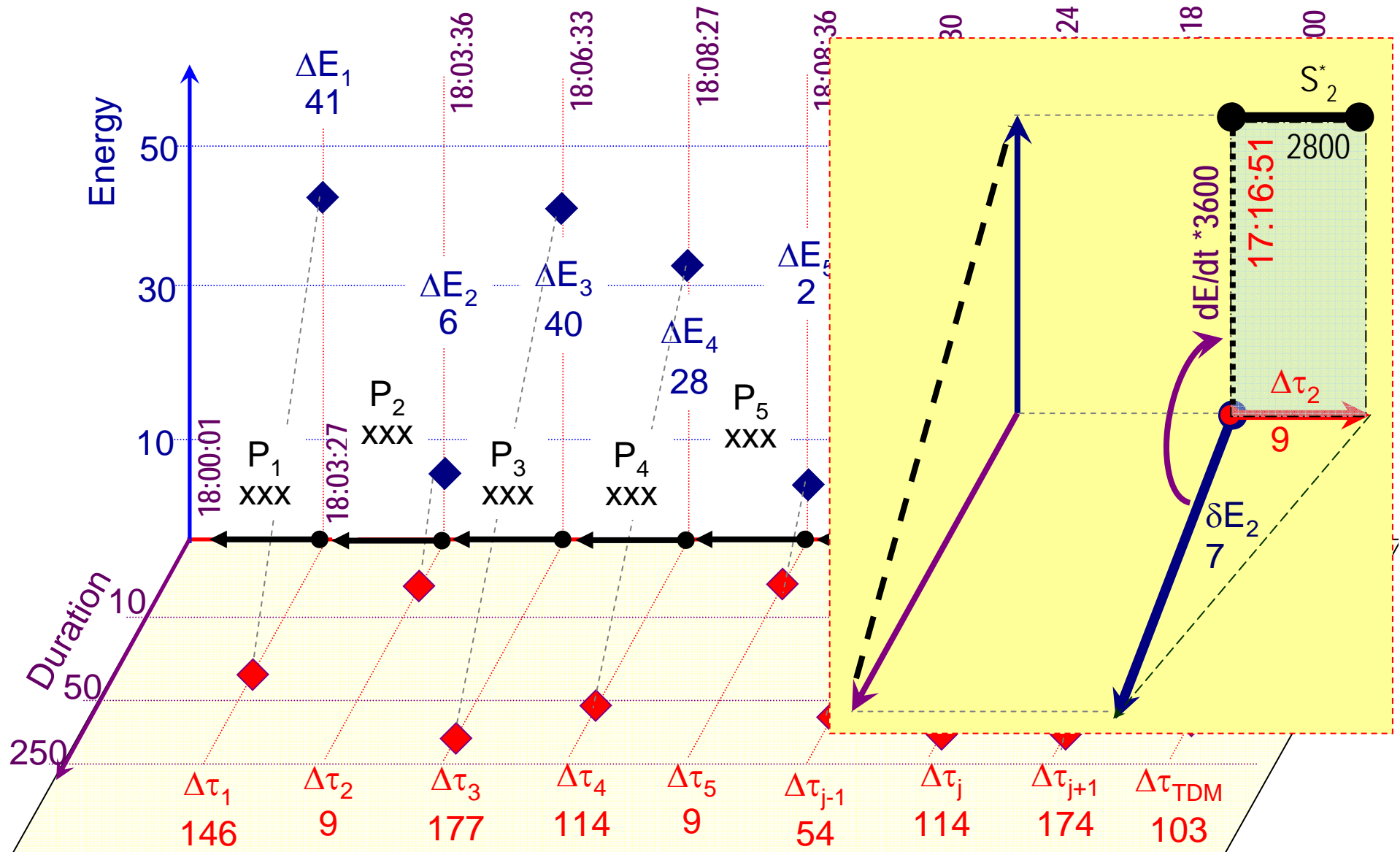
$$(dE_1 + dE_2 + \dots + dE_j) < \delta E \rightarrow \text{True}$$



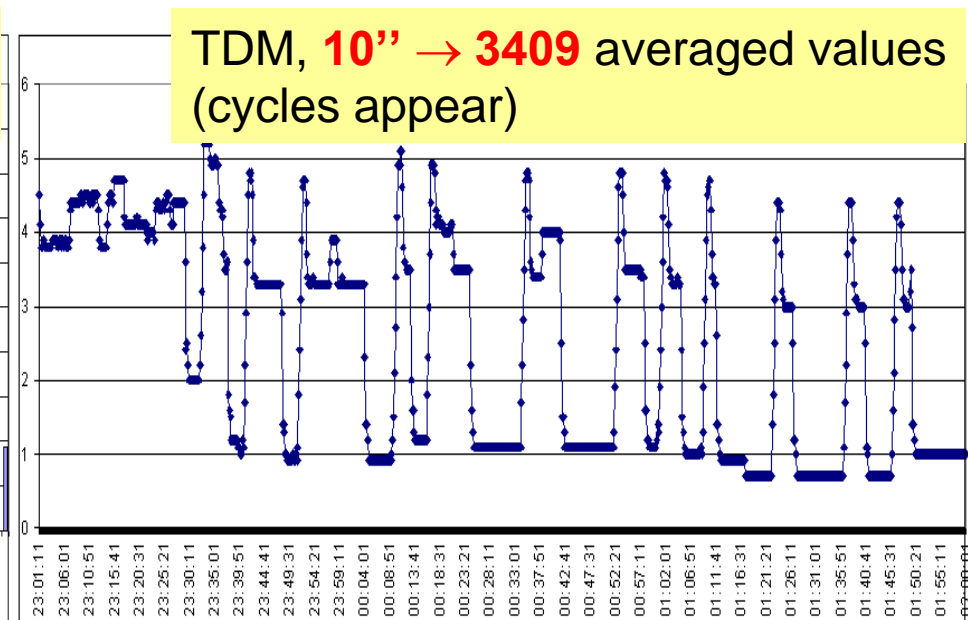
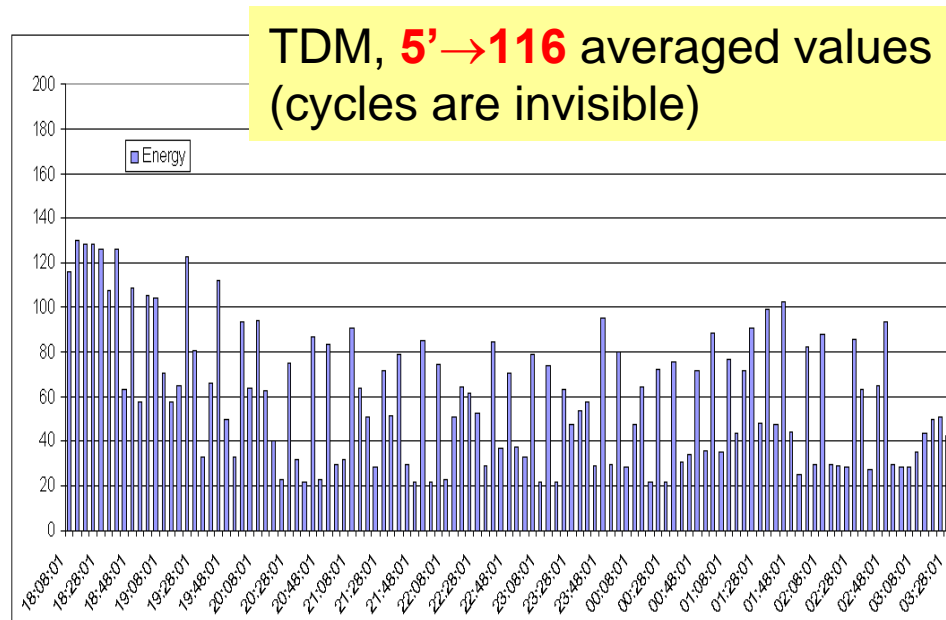
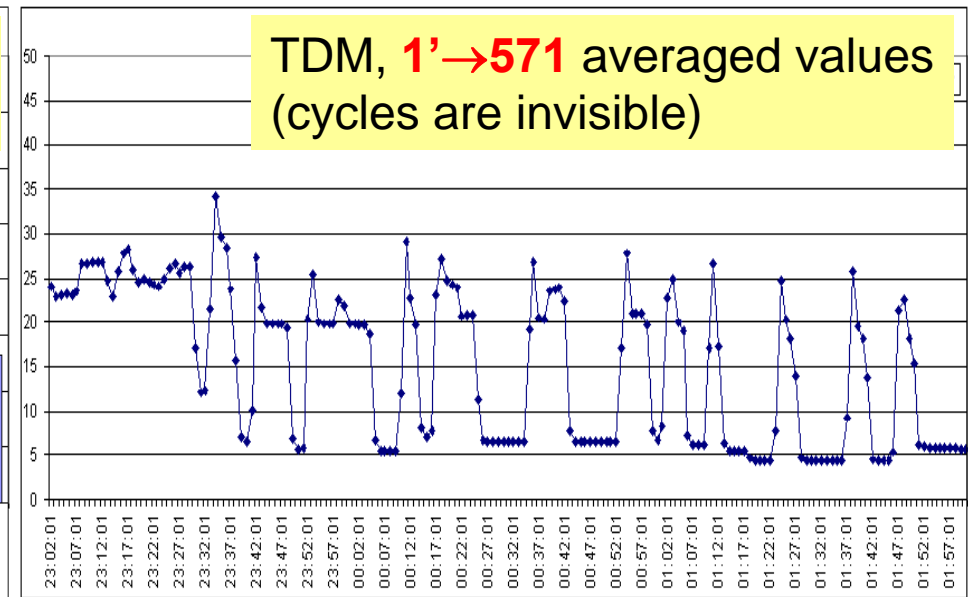
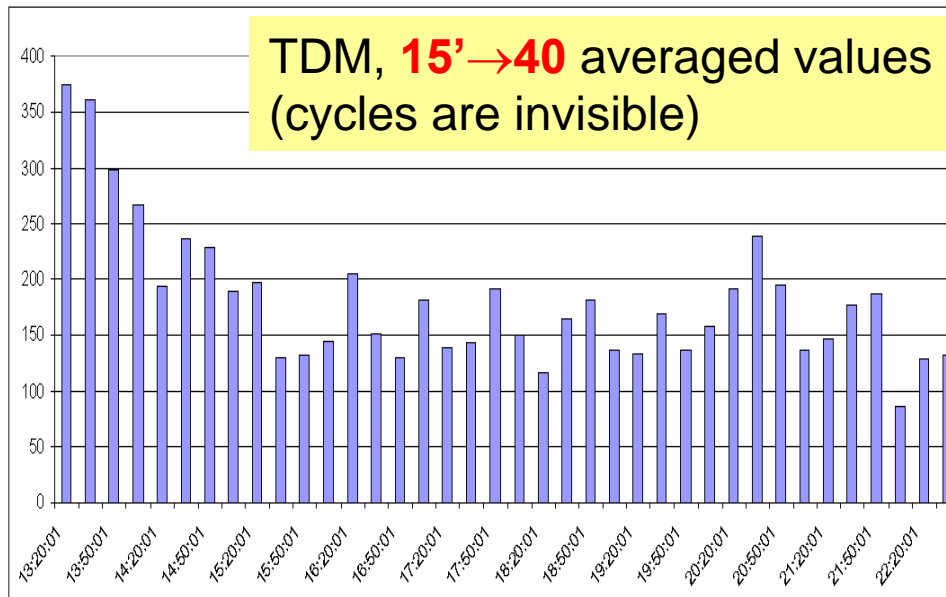
The coarse-grained event-driven metering methods generate chains

$\{E(t_j), t_j, \Delta t_j\}$ and $\{\Delta E(t_j), t_j, \Delta t_j\}$

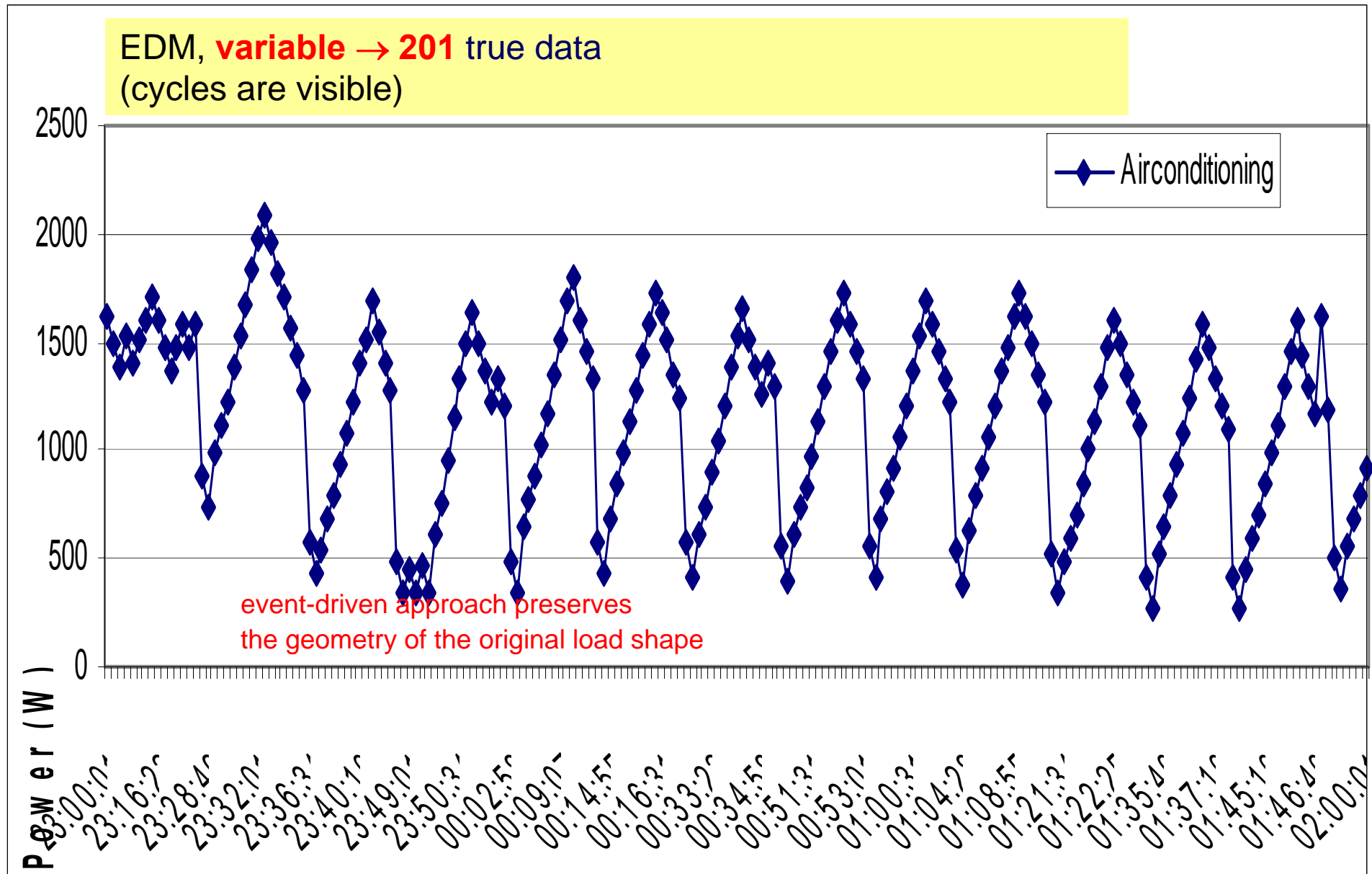
The CMCA method supplies 4-dimensional dataset $\{\Delta E(t), t\}$ and $\{\Delta t, t\}$



The same time period (3h) is described analytically by fewer CMCA data items.



The same time period (3h) is described analytically by fewer CMCA data items.

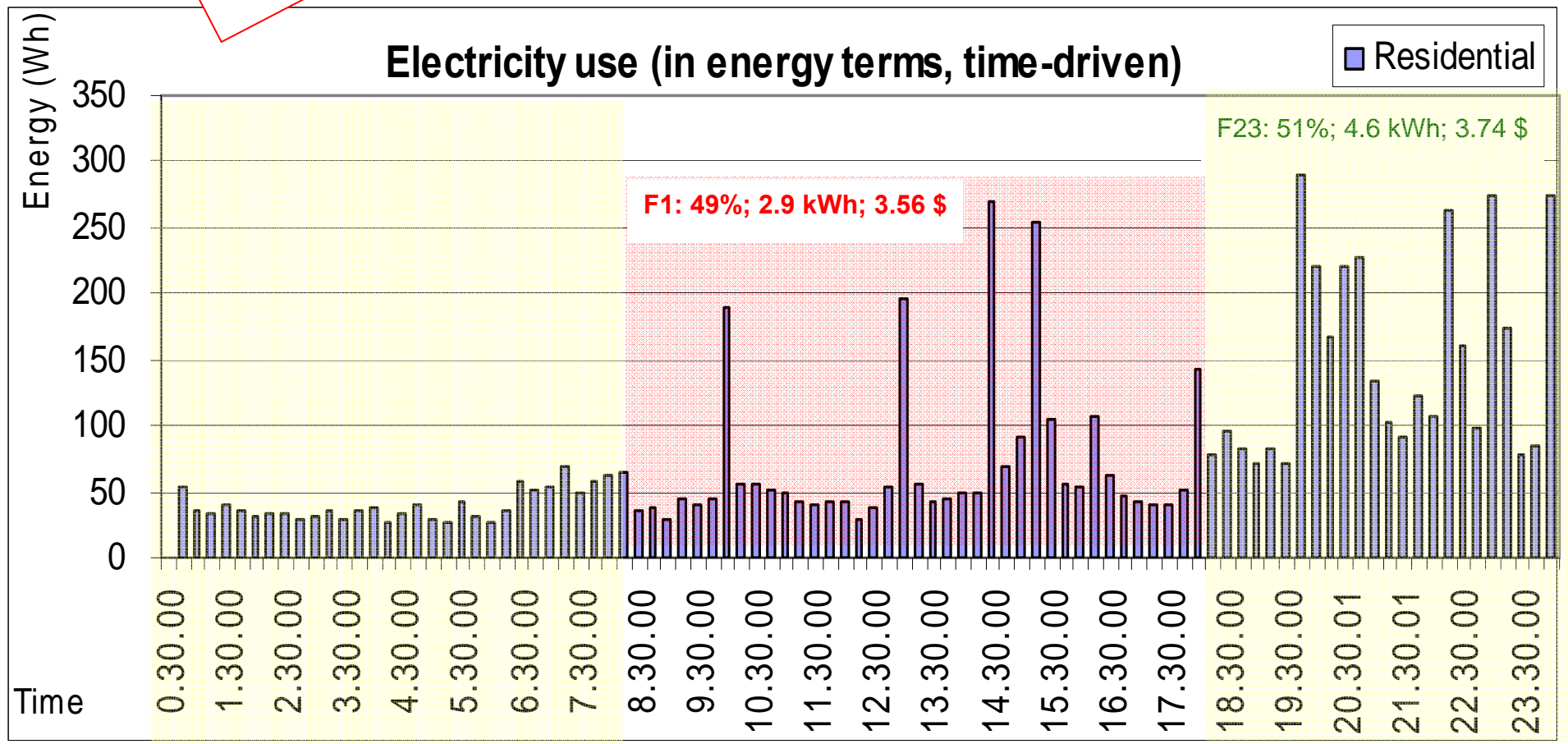


Legacy billing

The Electric Corp.

Energy Bill (from 11/02/2011 to 12/02/2011)

Time-driven
uniform time

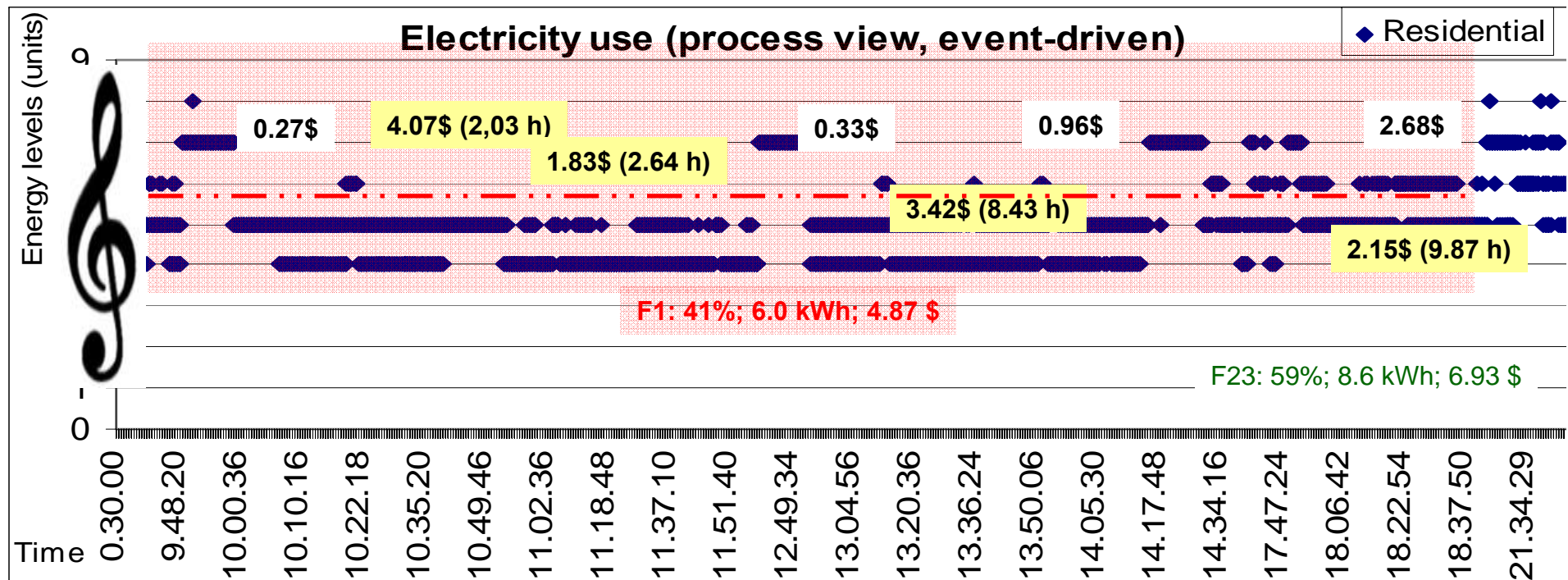


Process-oriented billing by CMCA

The Electric Corp.

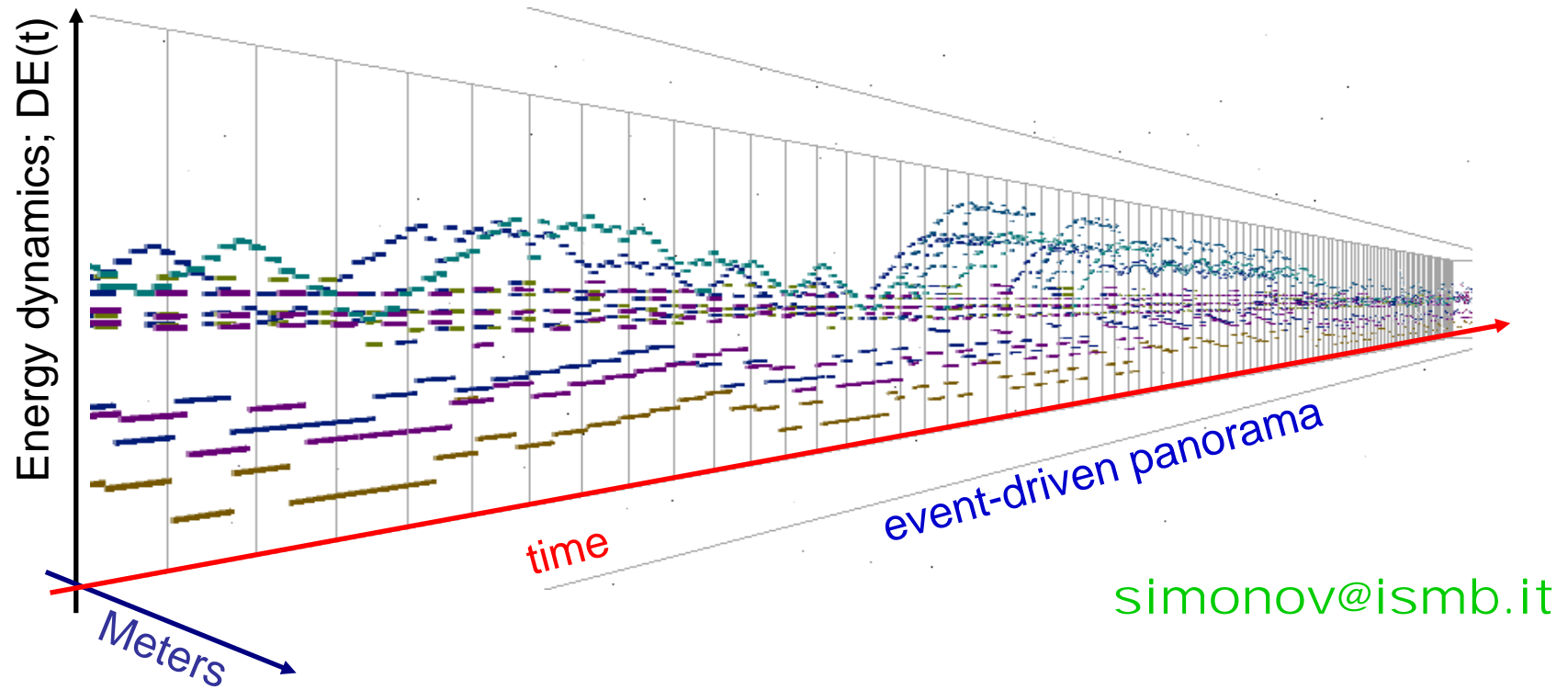
The Same Energy Bill (from 11/02/2011 to 12/02/2011)

Process view
SOA/EDA
compressed time





THANK YOU - TEŞEKKÜR EDERİM



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