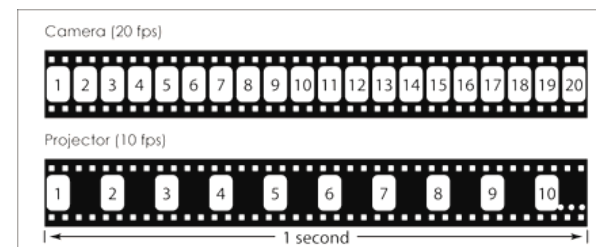




# Coarse-grained cycle-accurate method (analytical accounting of electricity)

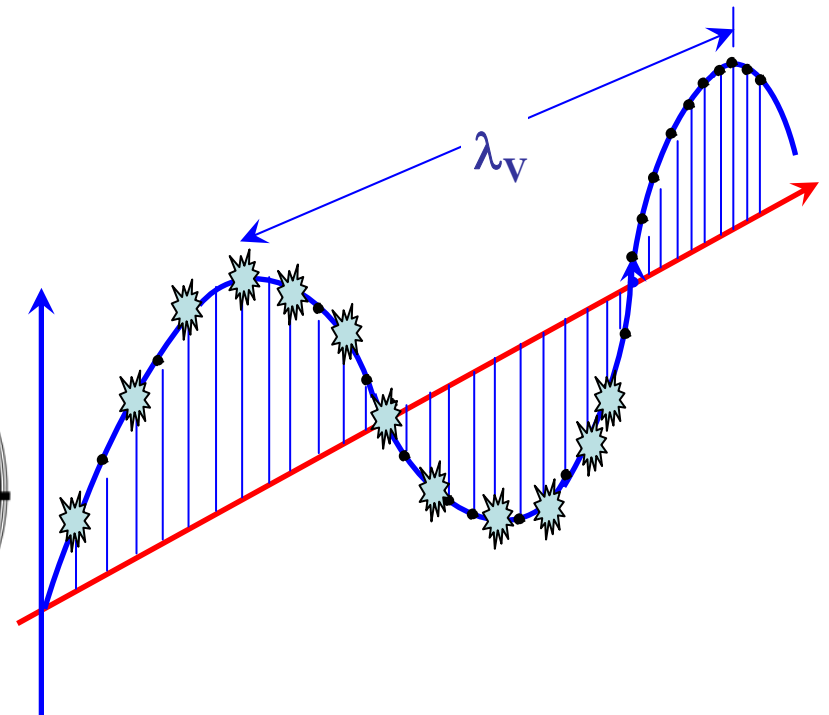
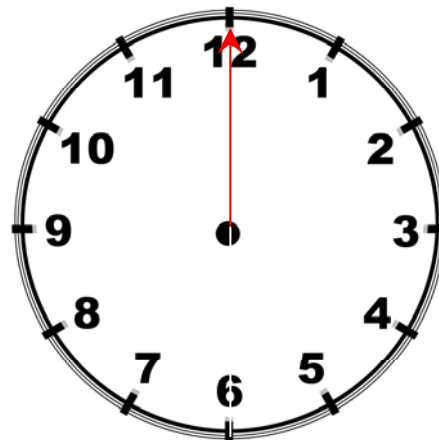
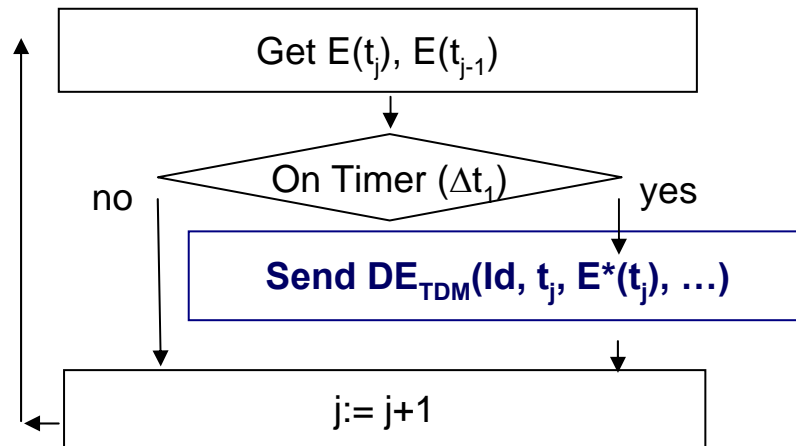
Mikhail Simonov, Ph.D.  
simonov@ismb.it



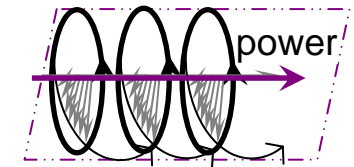
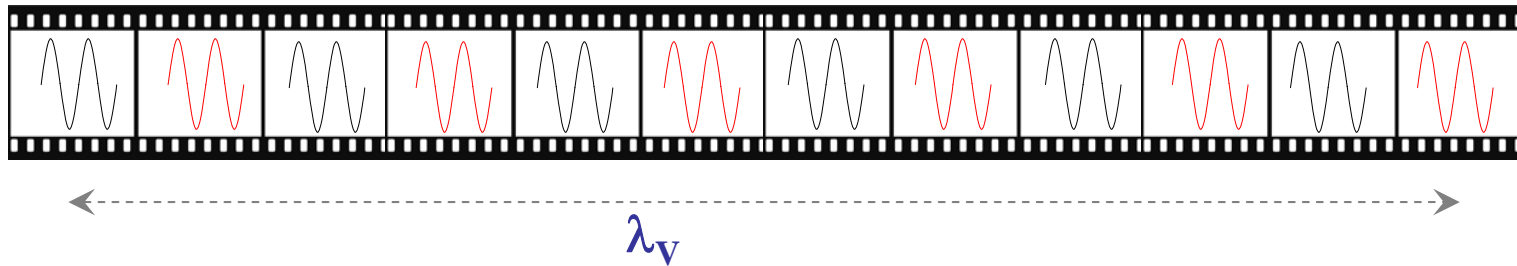
Inside **timer-driven meters**, the waveforms of electricity are observed *by using frequent time sampling (32 kHz = 640 samples per AC cycle; every 31  $\mu$ s).*

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

32,000 fps



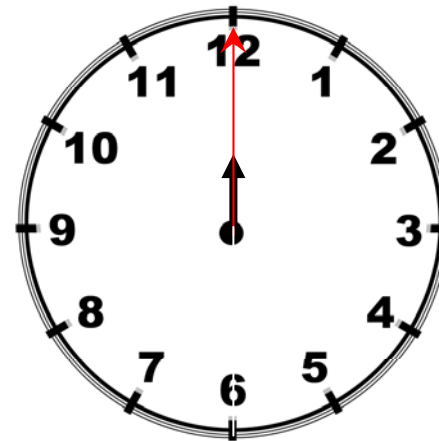
Fine-grained **energy-per-interval** integrals are computed based on the above samples of **voltages** and **currents** taken in the **local discrete time**.  
 Fine-grained data (50 packets per second) cannot be shared network-wide.



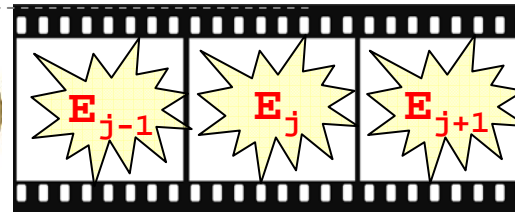
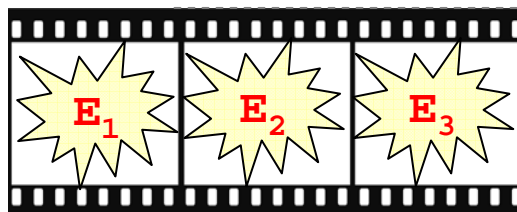
32,000 fps

```

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;
    
```

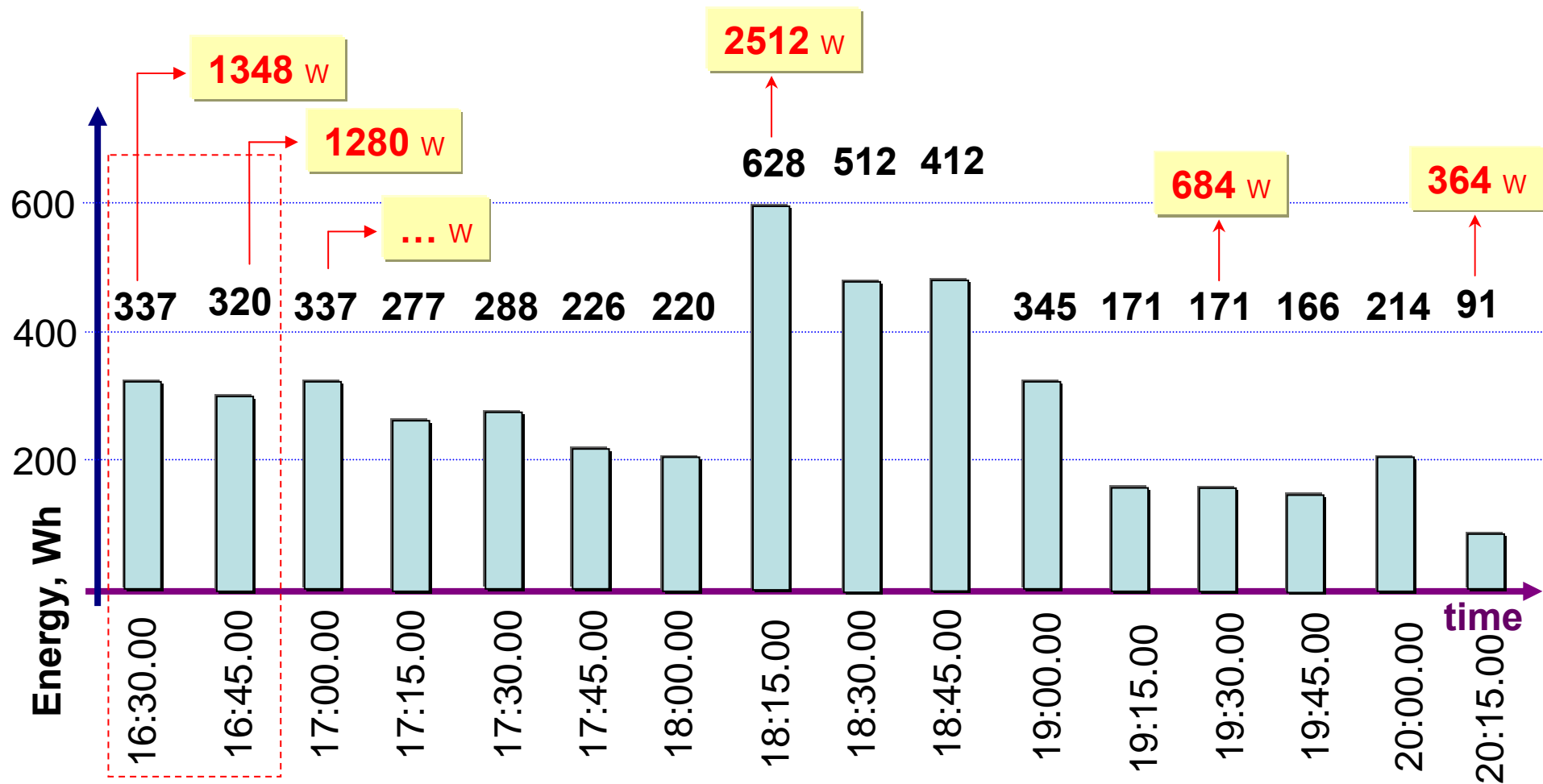


50 (60) fps



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.



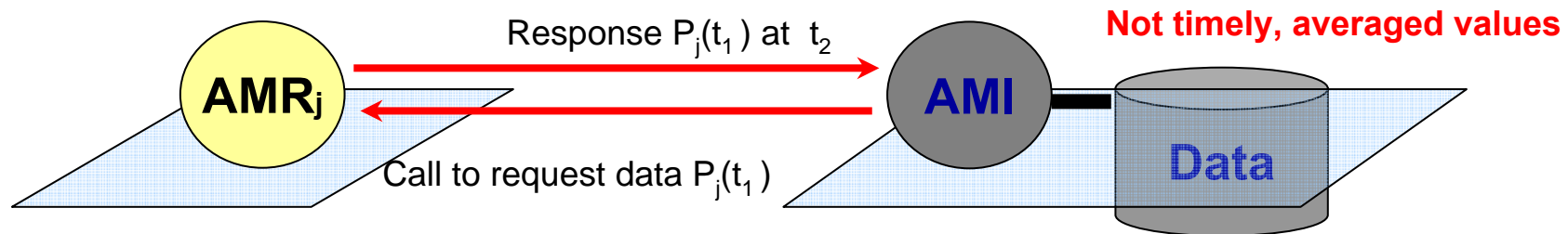
Averaged pseudo-measurements of *energy-per-interval* **can be derived** every 15'

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.

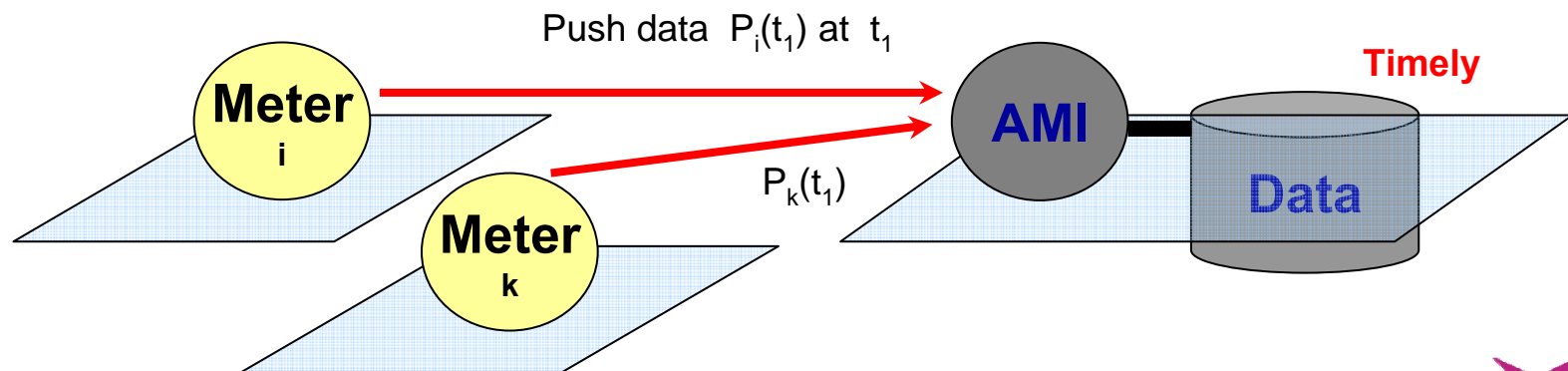
Data traffic (100%) = requests-for-data (50%) + replies (50%).



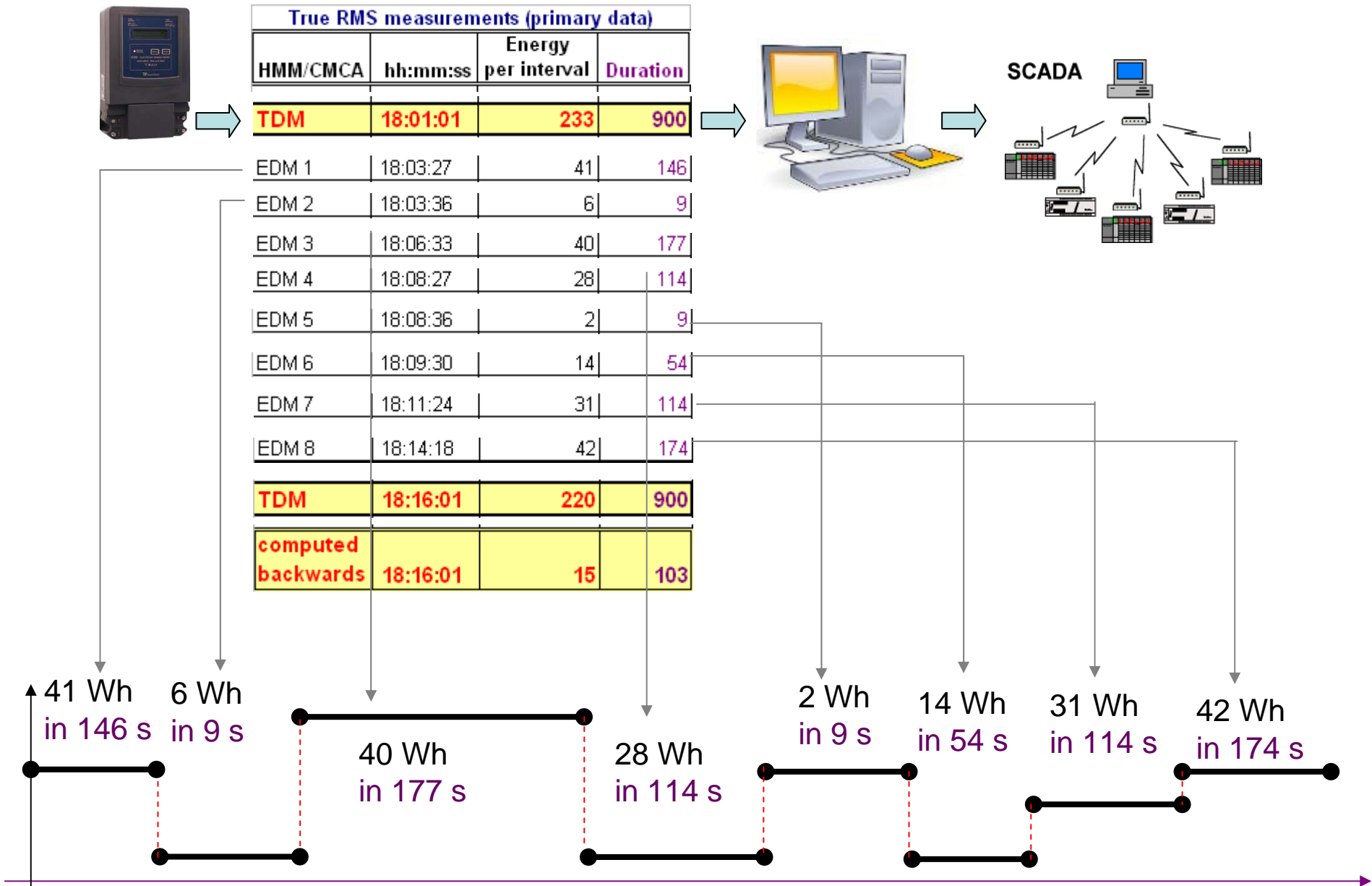
In **event-driven approach**, meters push data, while the AMI host listens.

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

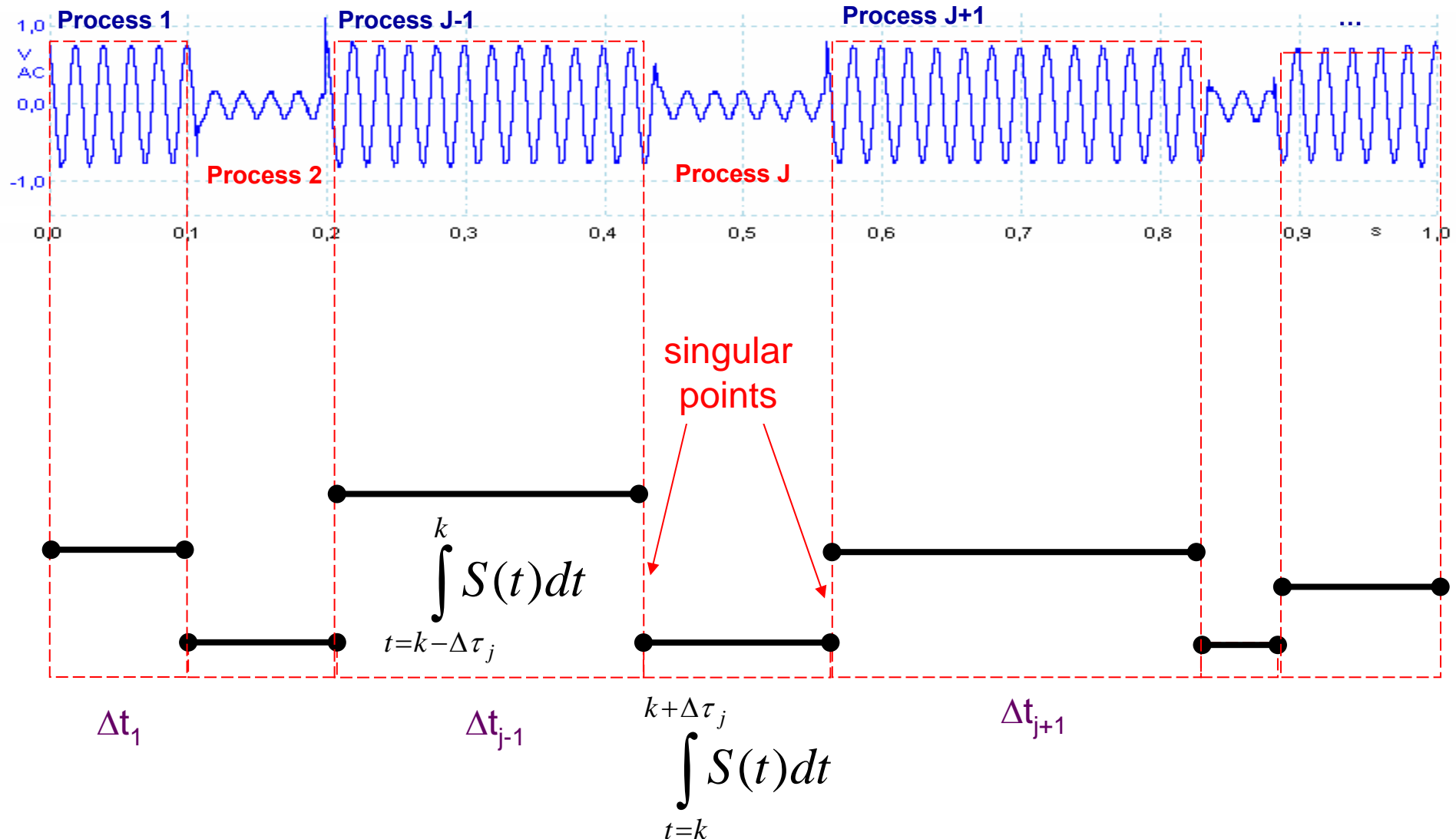
We **halved the data traffic**.



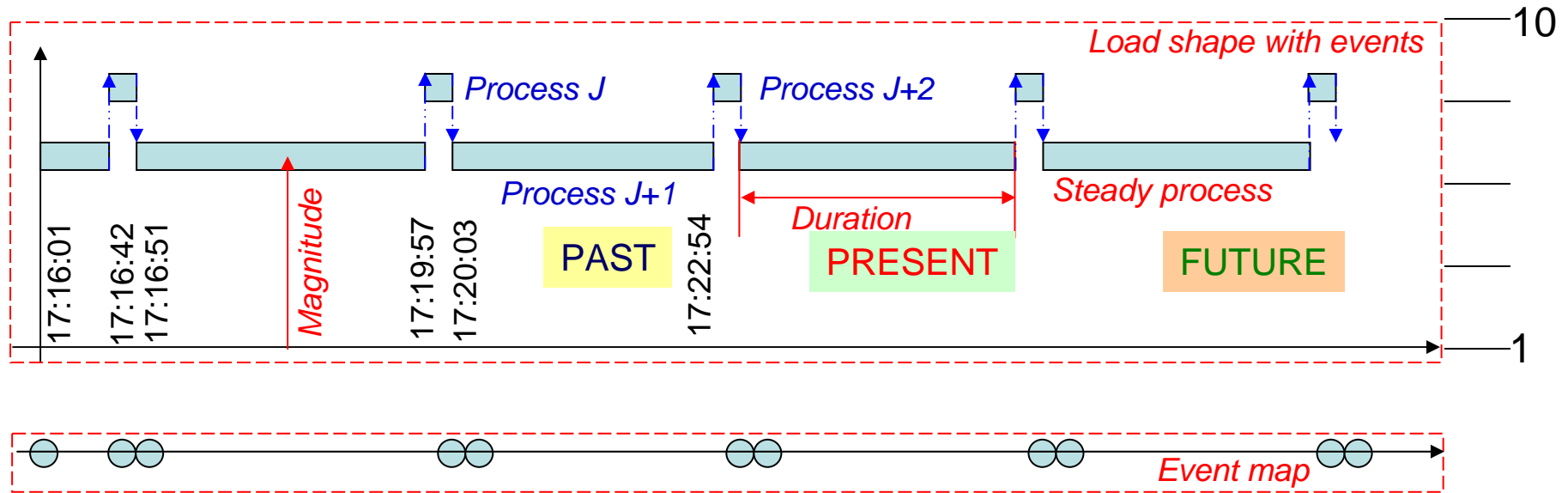
In event-driven approach, meters send **events** in real-time, **record-by-record**.  
 The **chain of process-oriented segments** (chunks) appears.



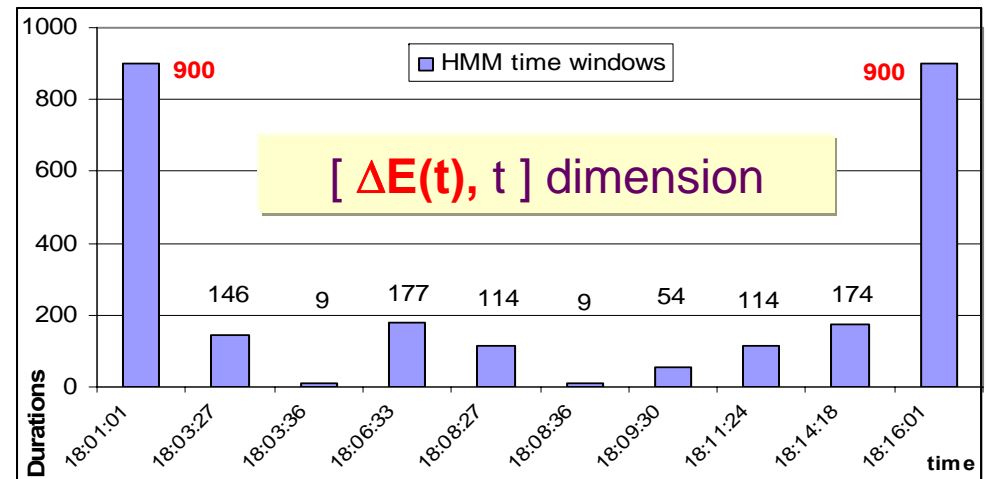
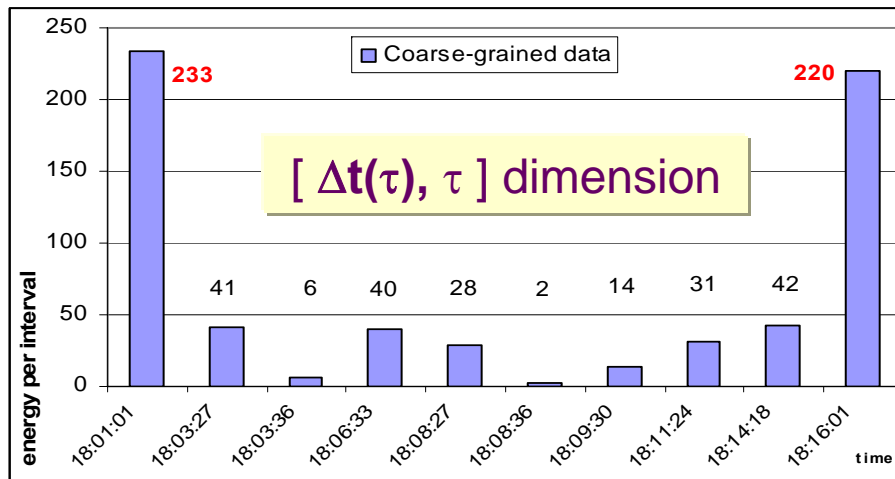
Steady **power** (periods) imply **duplicates** of the **energy-per-interval**.  
 Geometric integration (change→point) originates a polygonal line.  
 The time is now partitioned in finite segments flowing at **non-uniform rates**.  
 Each change → a singularity → derivative of energy does not exist.



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



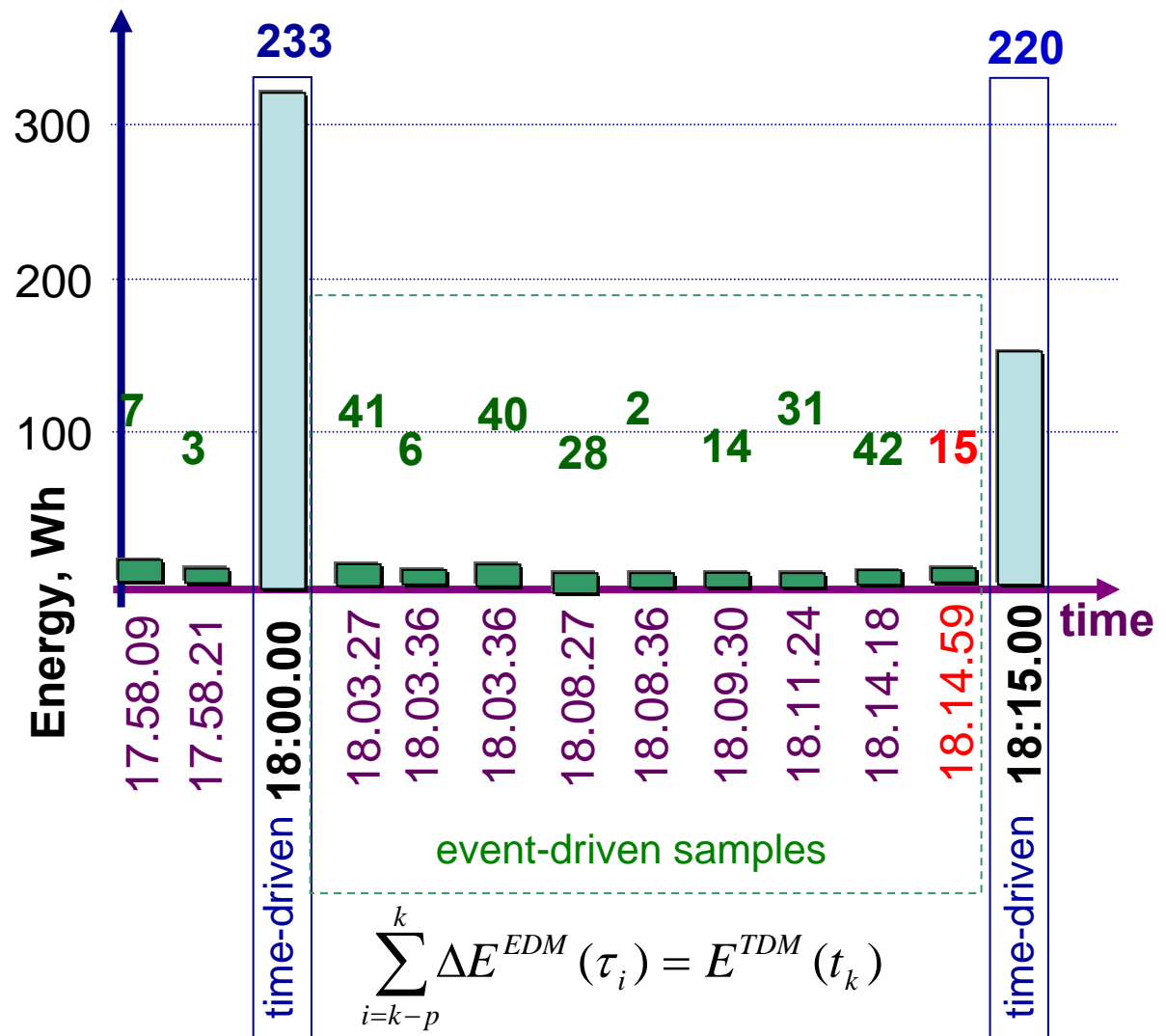
We got 2 bi-dimensional data sets (e.g. one 4-D data object) to visualize.





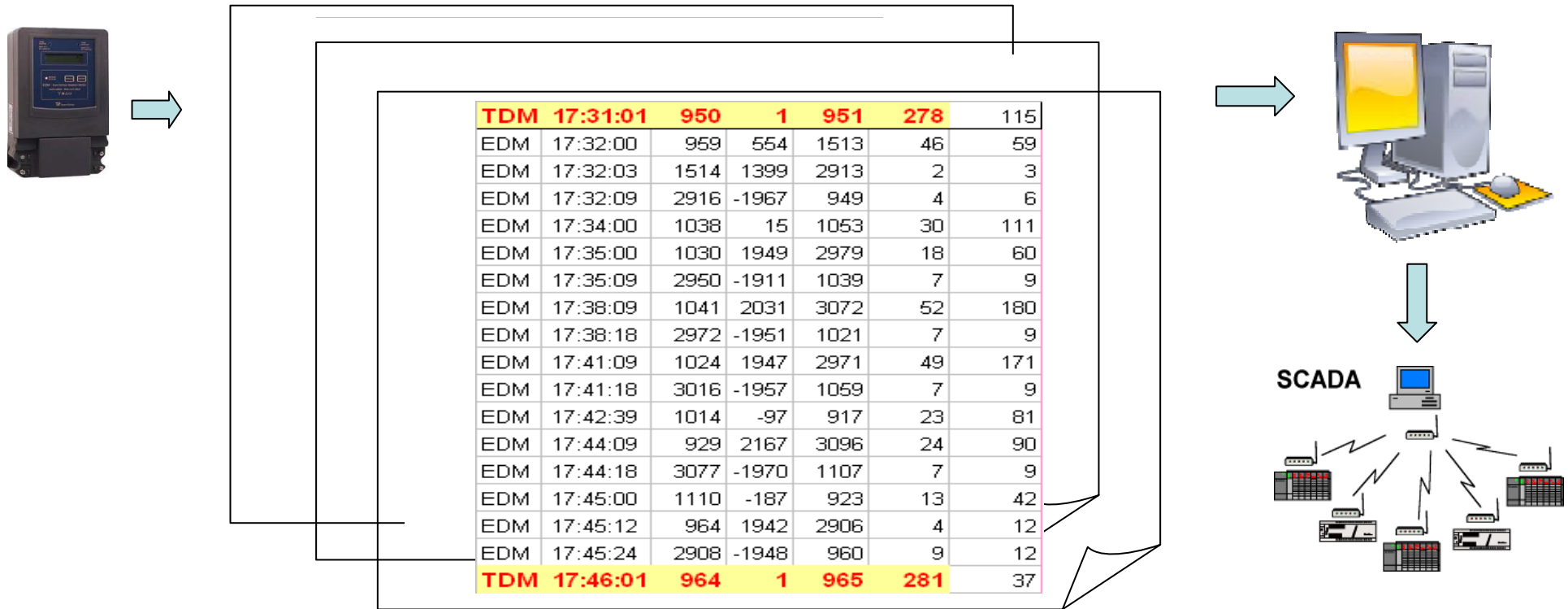
Infrequent averaged timer-driven values are used as **reference frames** (time windows)  
 True rms measurements of **energy-per-interval** come upon events in real time  
 Coarse-grained method delivers **process knowledge** (timestamp + magnitudes + duration)  
 It lets compute important values: the **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
<b>TDM</b>	<b>18:01:01</b>	<b>233</b>	<b>900</b>
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
<b>TDM</b>	<b>18:16:01</b>	<b>220</b>	<b>900</b>
<b>computed backwards</b>	<b>18:16:01</b>	<b>15</b>	<b>103</b>

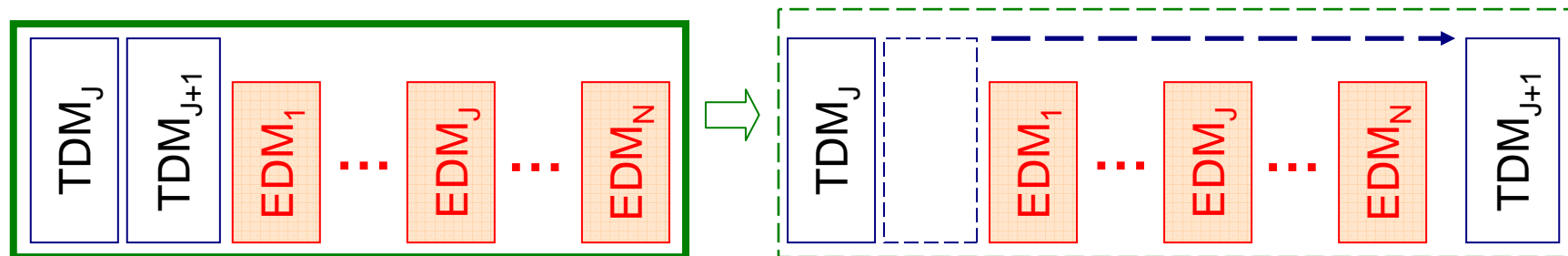


When the real-time horizon is not required, but the analytical data is welcome,  
 We send analytical energy **data in batches** only.

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



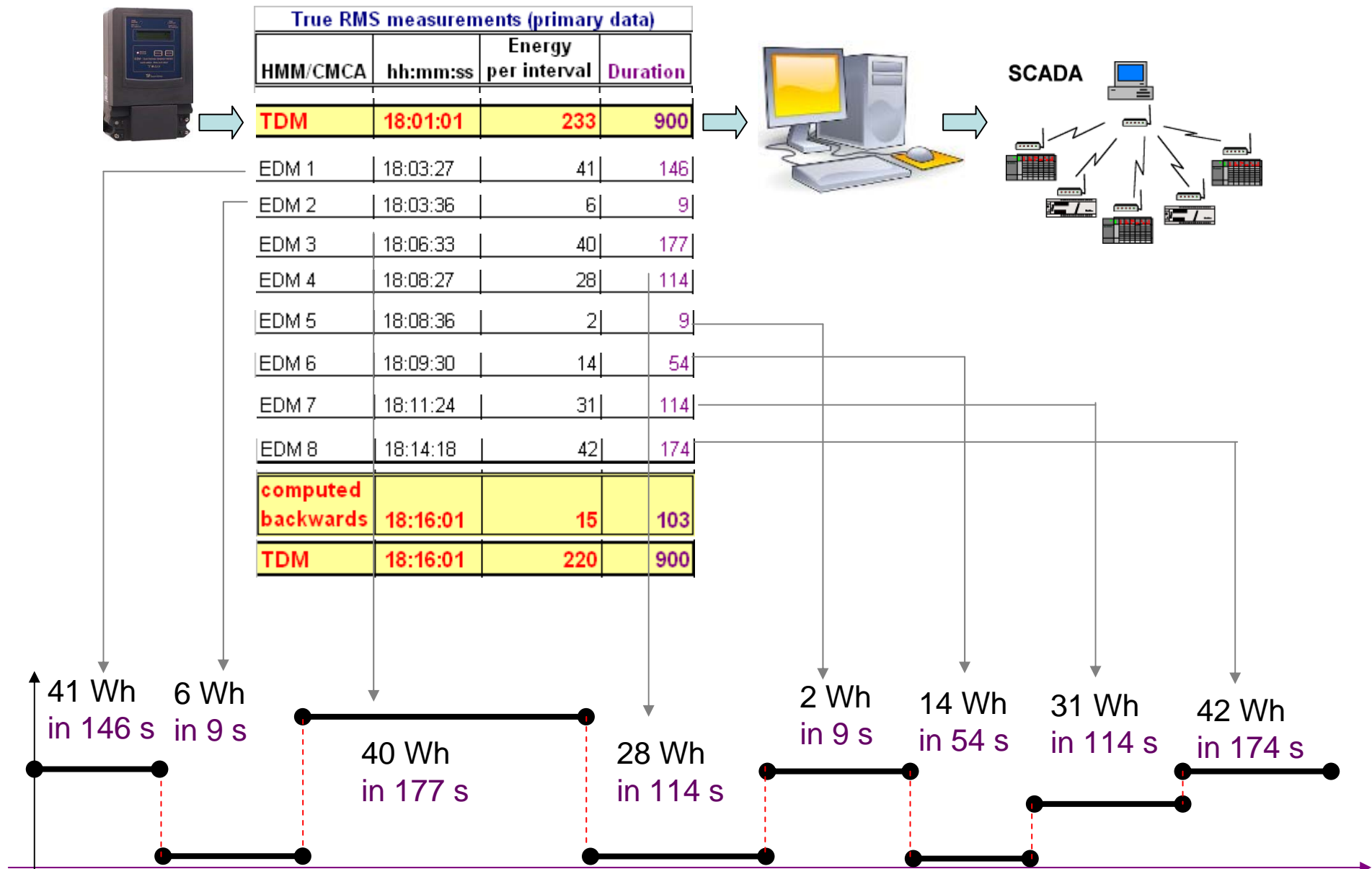
The only need is to re-order frames.



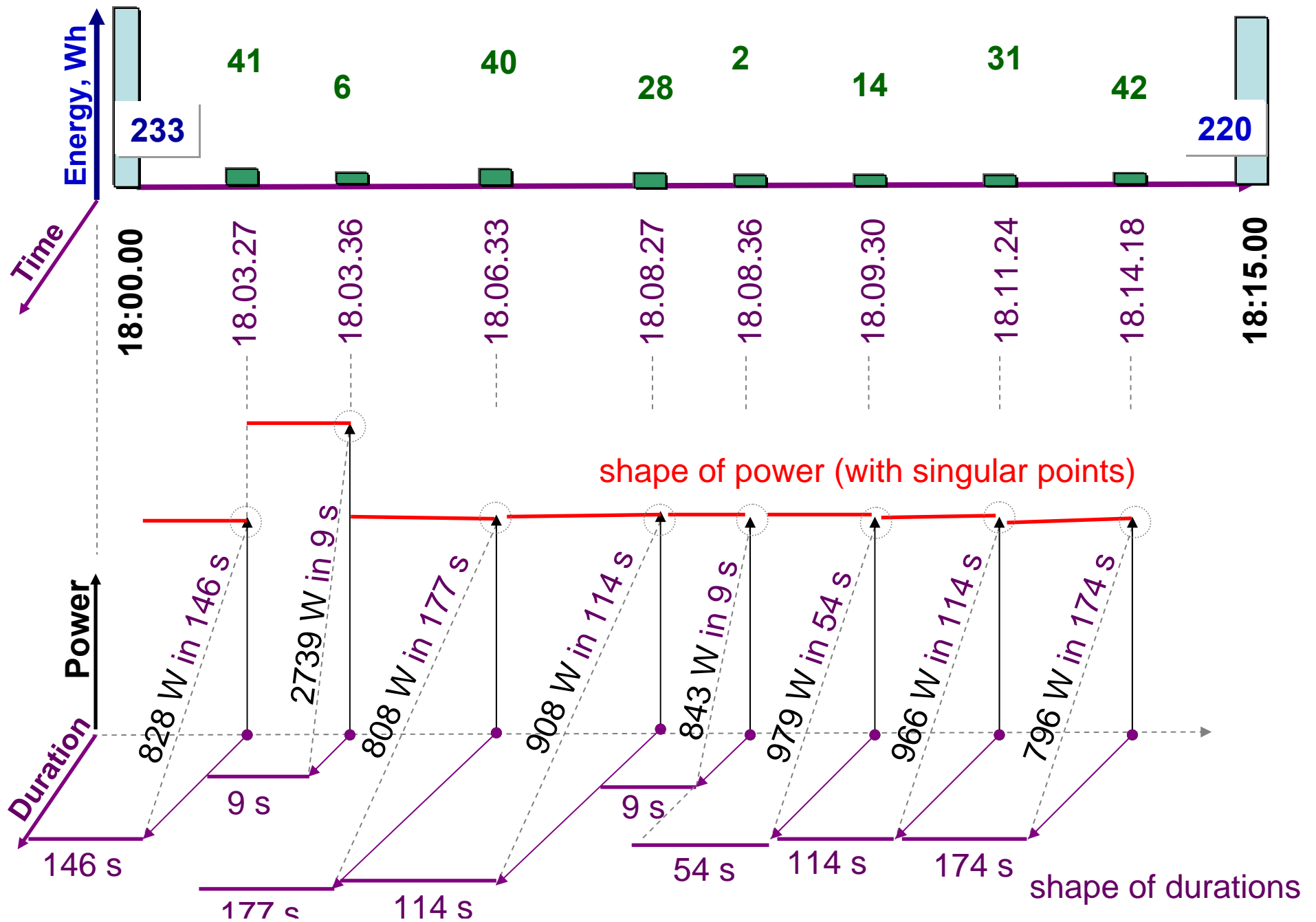
In CMCA approach, meters send **events** in **batches, altogether**

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).

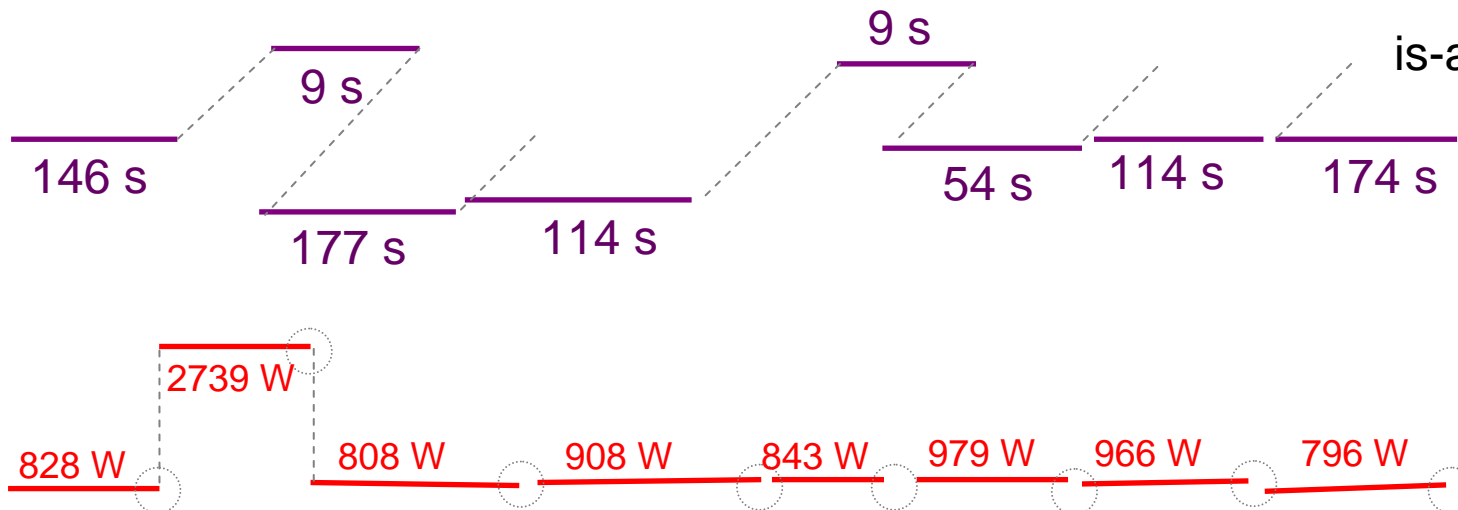


CMCA associates **costs** of energy to real-life **processes** (shown as **polyline**)

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

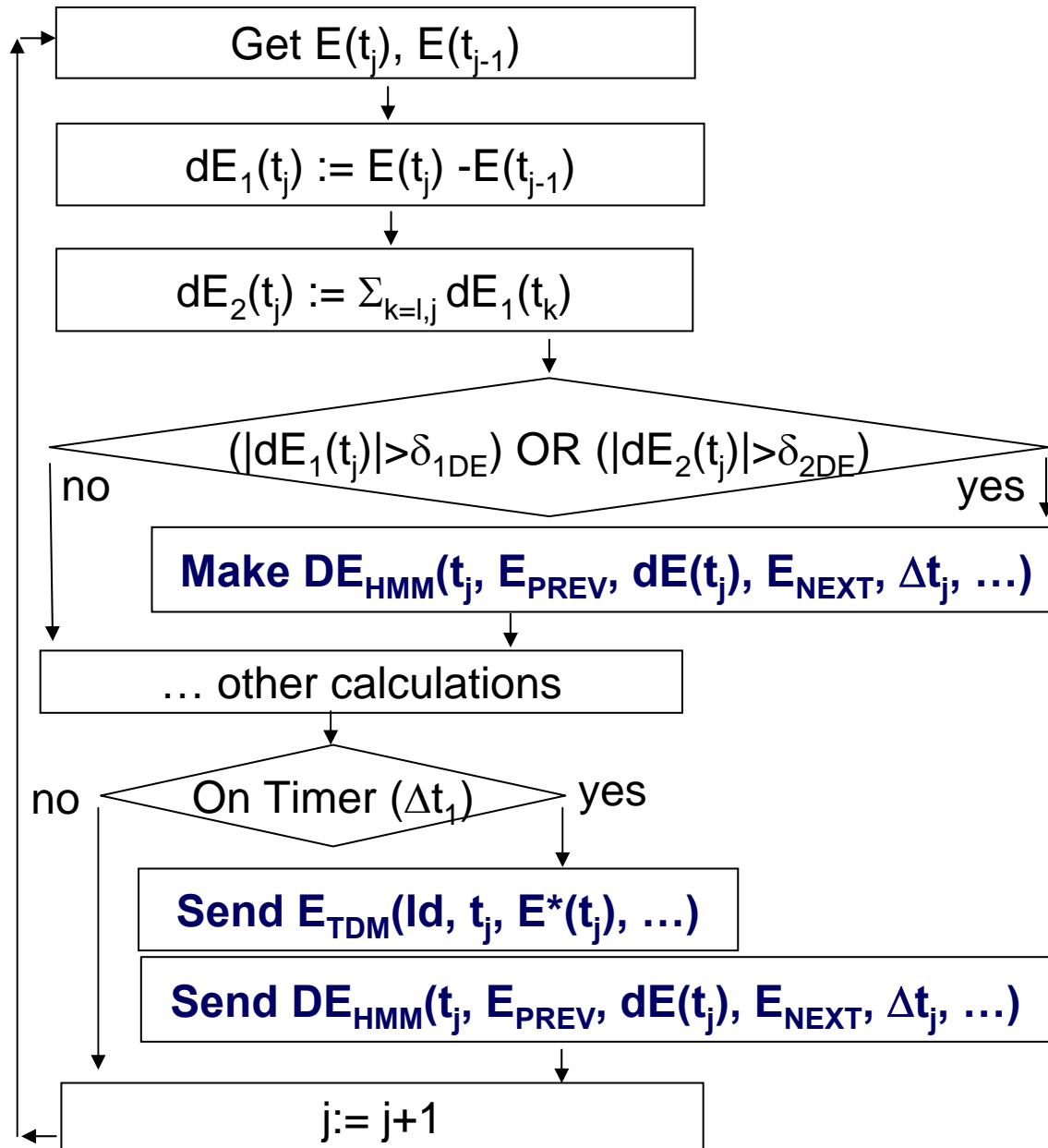
True RMS measurements (primary data)			
HMM/CMCA	hh:mm:ss	Energy per interval	Duration
<b>TDM</b>	<b>18:01:01</b>	<b>233</b>	<b>900</b>
EDM 1	18:03:27	41	146
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<b>computed backwards</b>	<b>18:16:01</b>	<b>15</b>	<b>103</b>

Computed values (derived data)					
Pprev	dP	Pimb	Accumulated energy	Pnext	Nota
<b>814</b>	<b>0</b>	<b>-10</b>	<b>1792</b>	<b>814</b>	<b>6</b>
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
<b>763</b>	<b>0</b>	<b>-5</b>	<b>2012</b>	<b>763</b>	<b>6</b>



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.

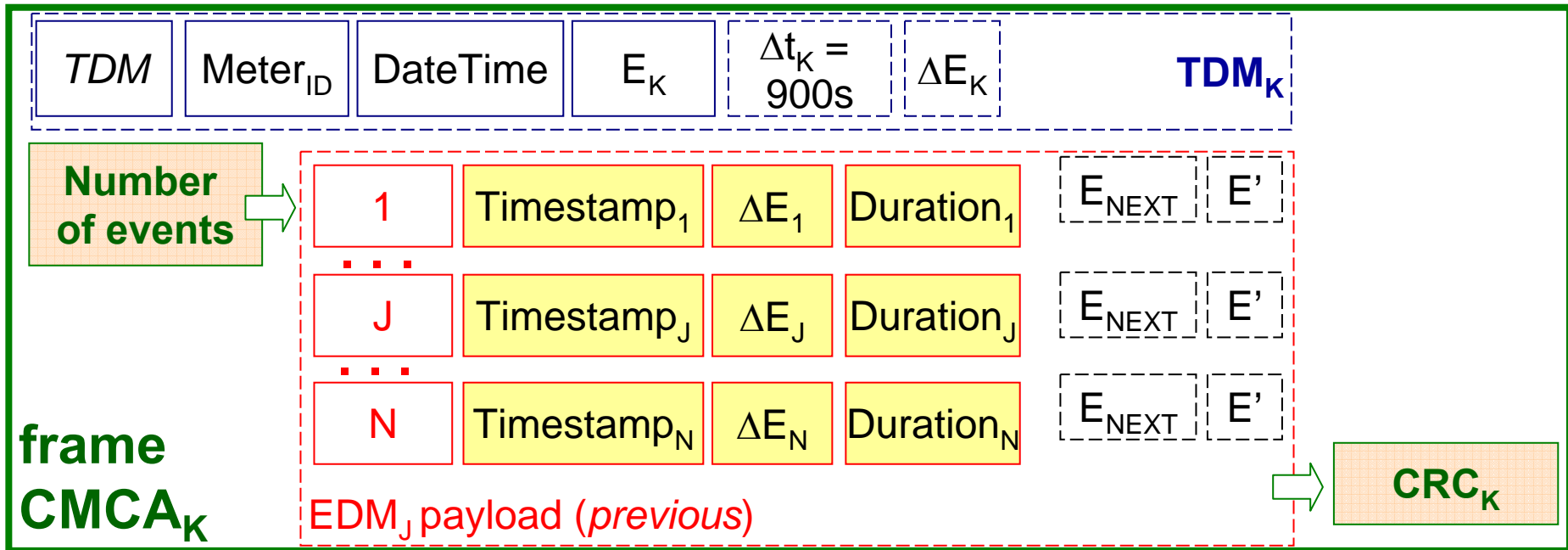


True RMS measurements (primary data)			
HMM/CMCA	hh:mm:ss	Energy per interval	Duration
TDM	18:01:01	233	900
EDM 1	18:03:27	41	146
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EDM 5	18:08:36	2	9
TDM	18:16:01	220	900

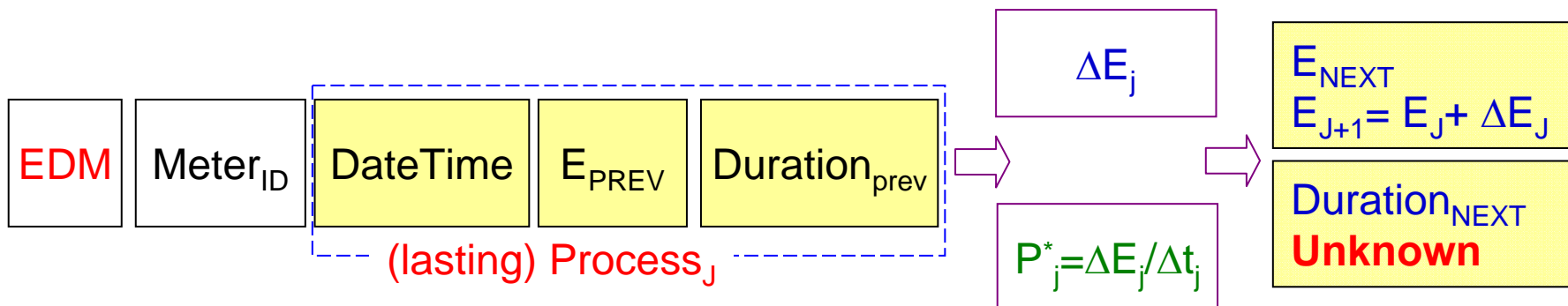
true stateful measurement (locally)

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

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



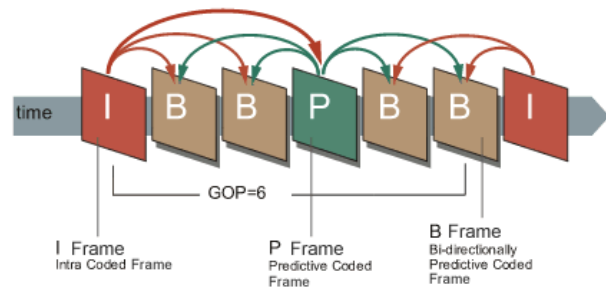
It enables the predictive computations...



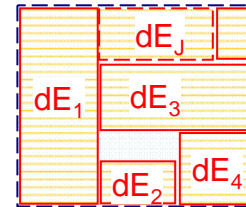
CMCA inherits from MPEG compression: absolute frames coming at regular time-intervals give sliding time-windows (as reference frames).

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

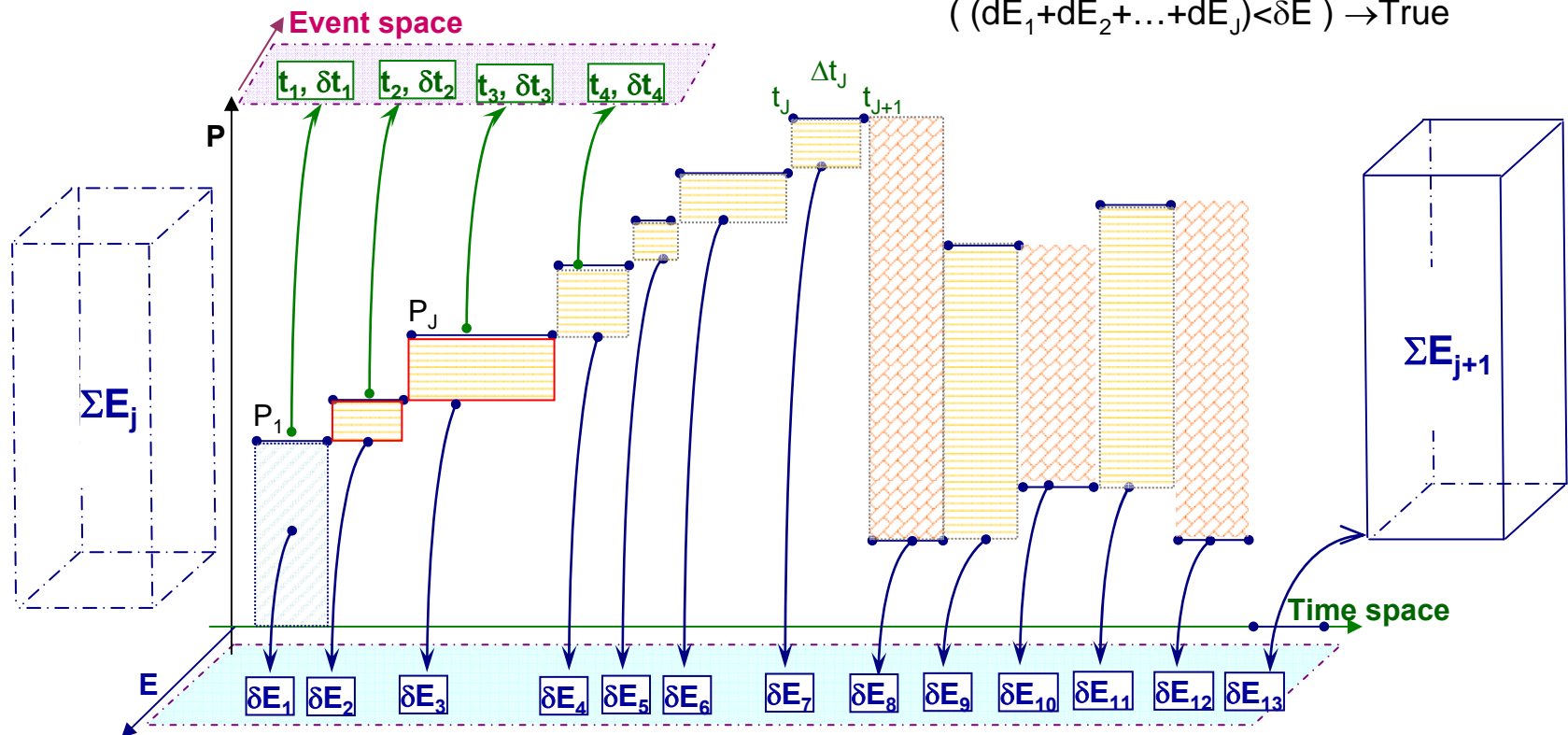
MPEG-2



“accumulated unbalance”



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

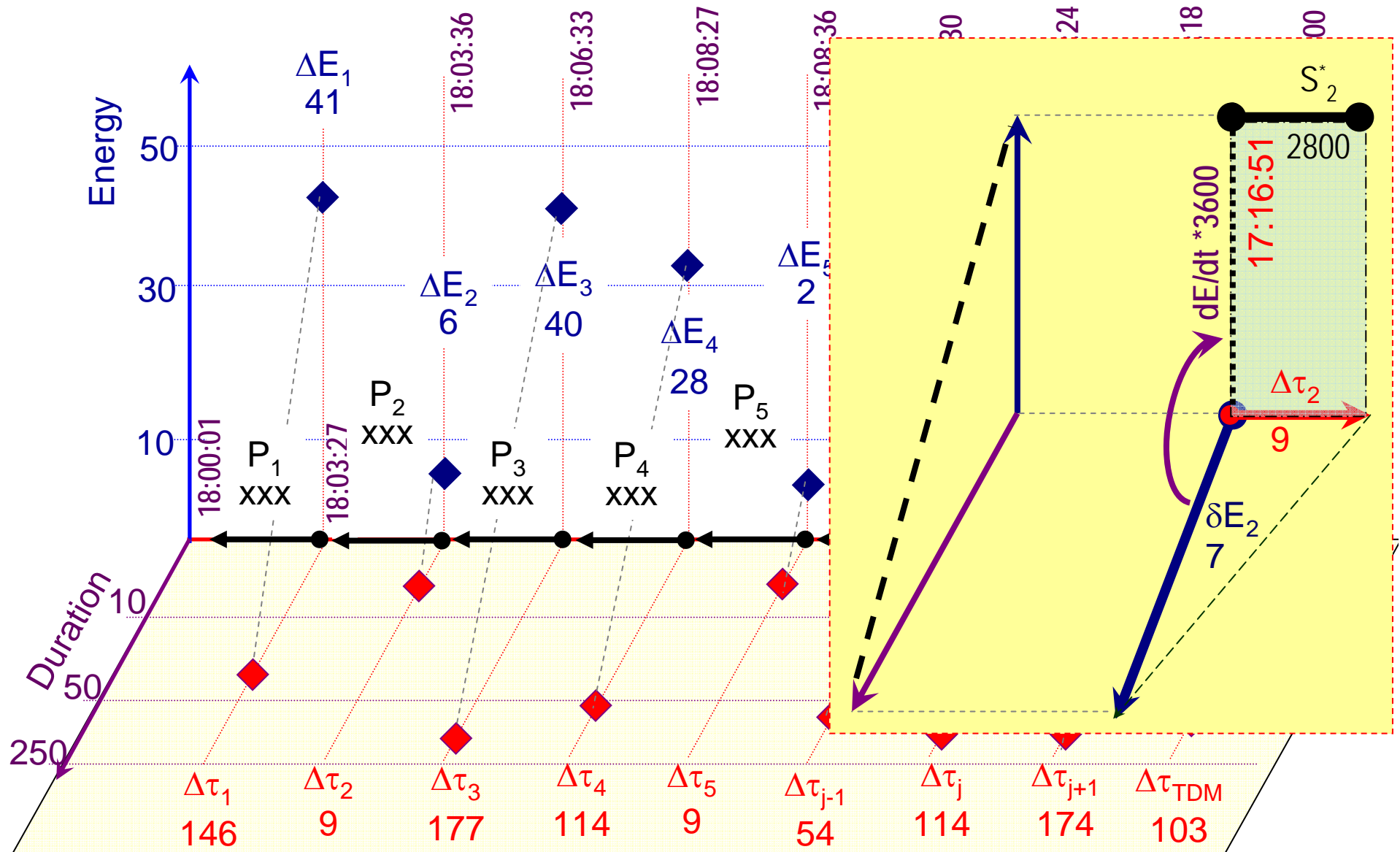




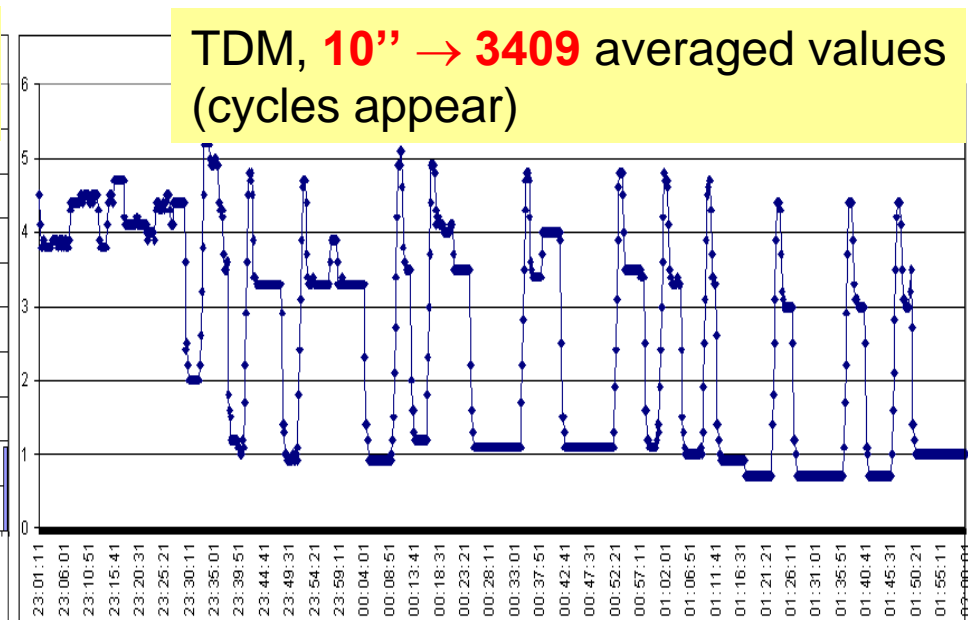
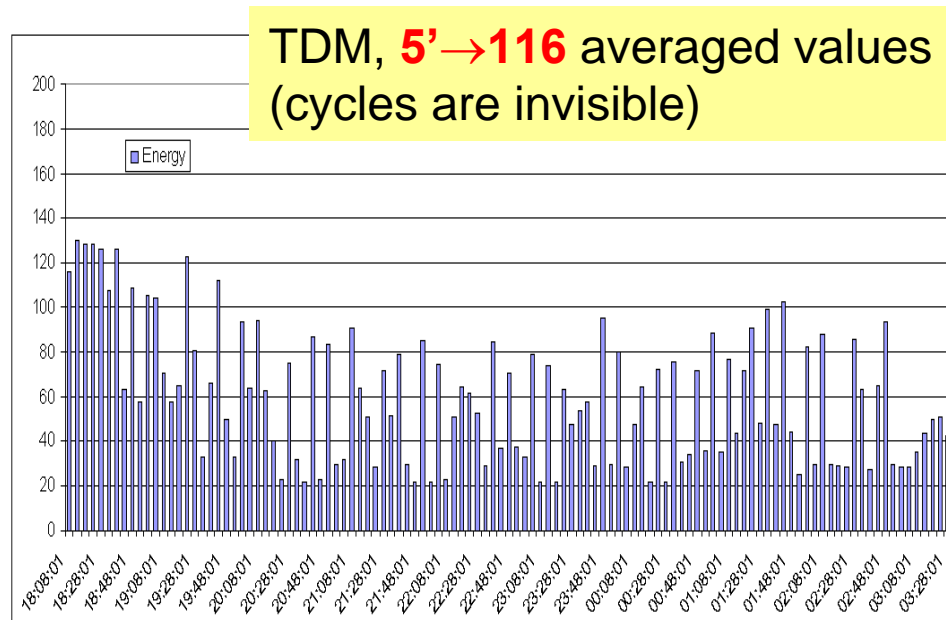
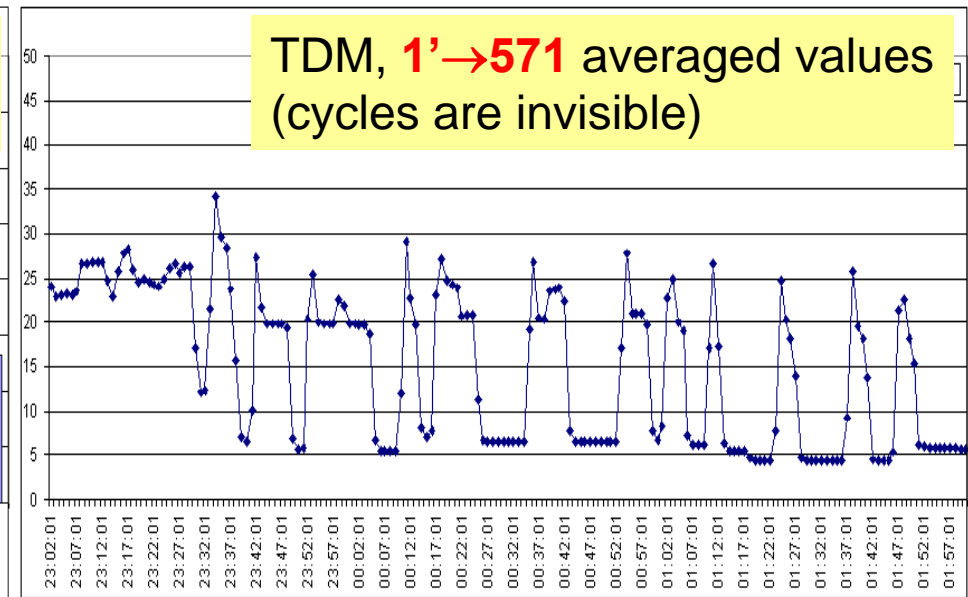
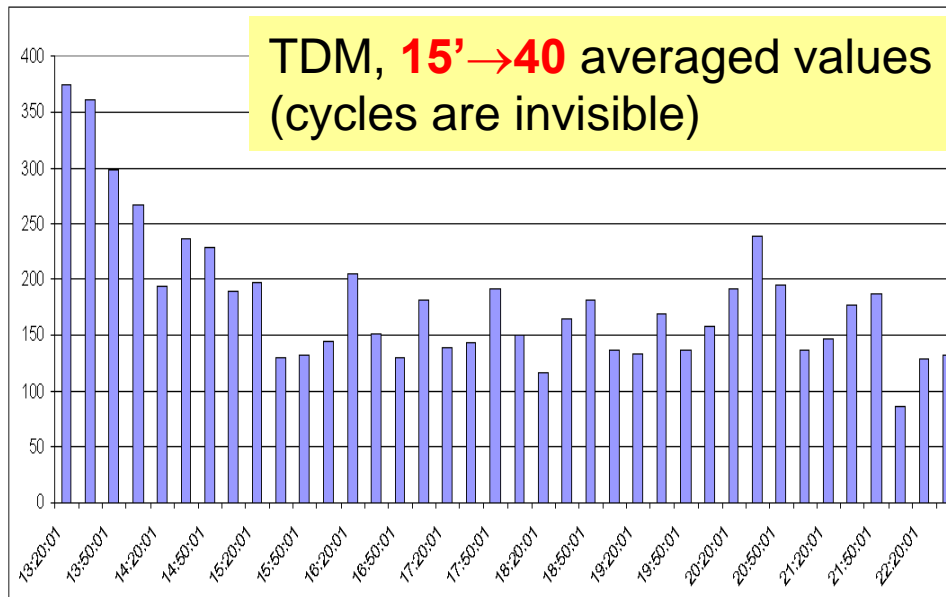
The coarse-grained event-driven metering methods generate chains

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

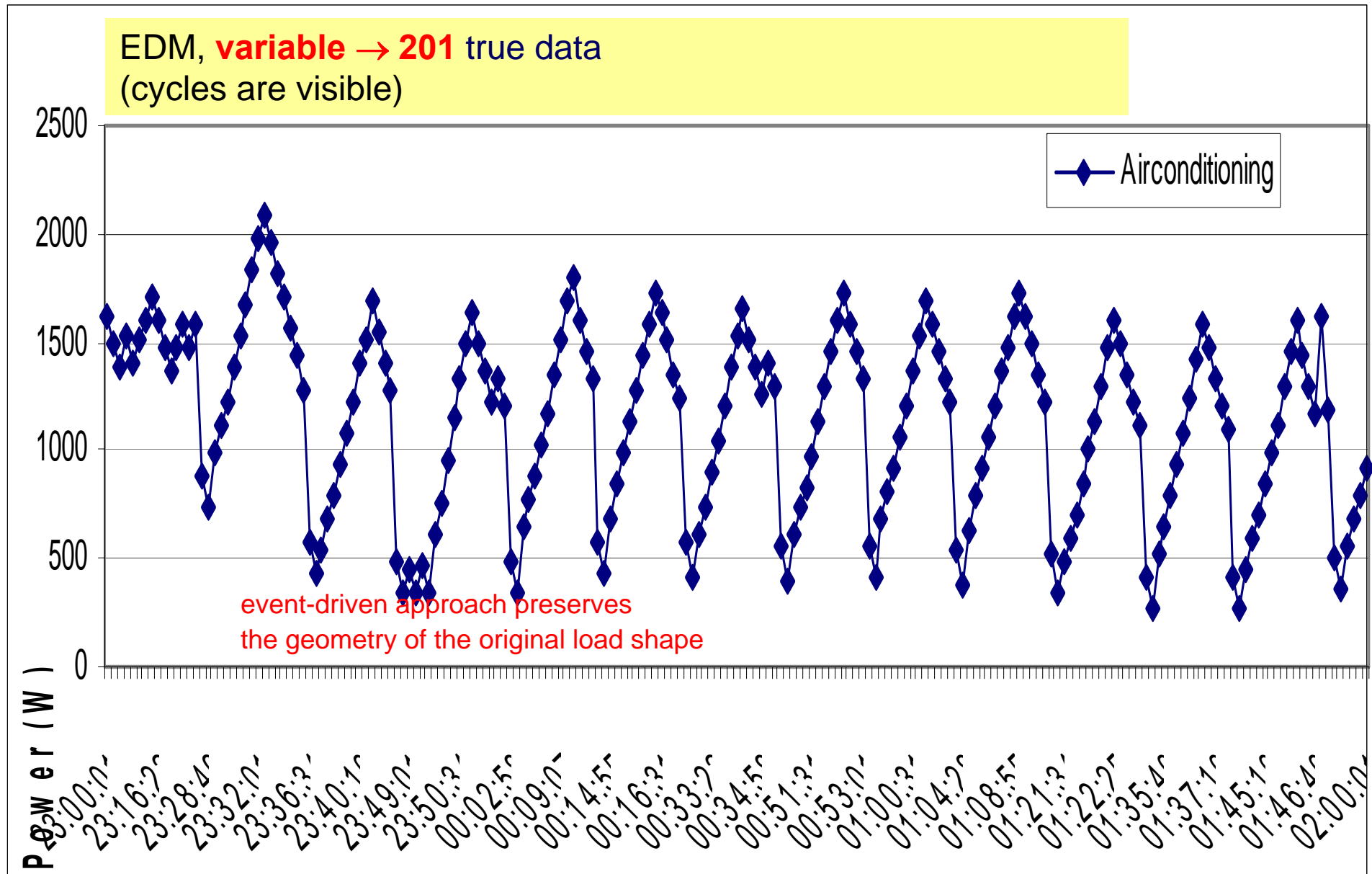
The CMCA method supplies 4-dimensional dataset  $\{\Delta E(t), t\}$  and  $\{\Delta t, t\}$



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.

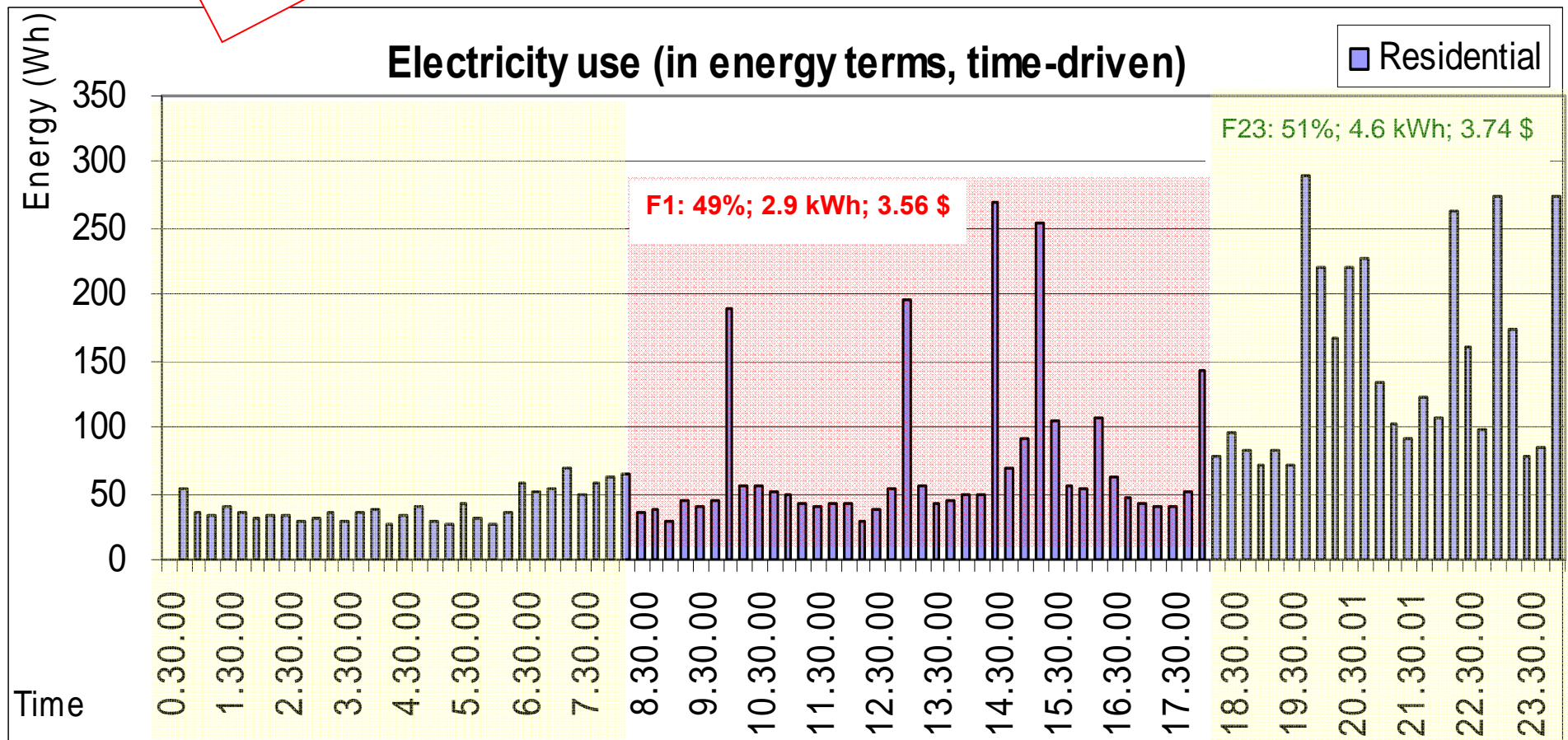


# Legacy billing

The Electric Corp.

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

Time-driven  
uniform time

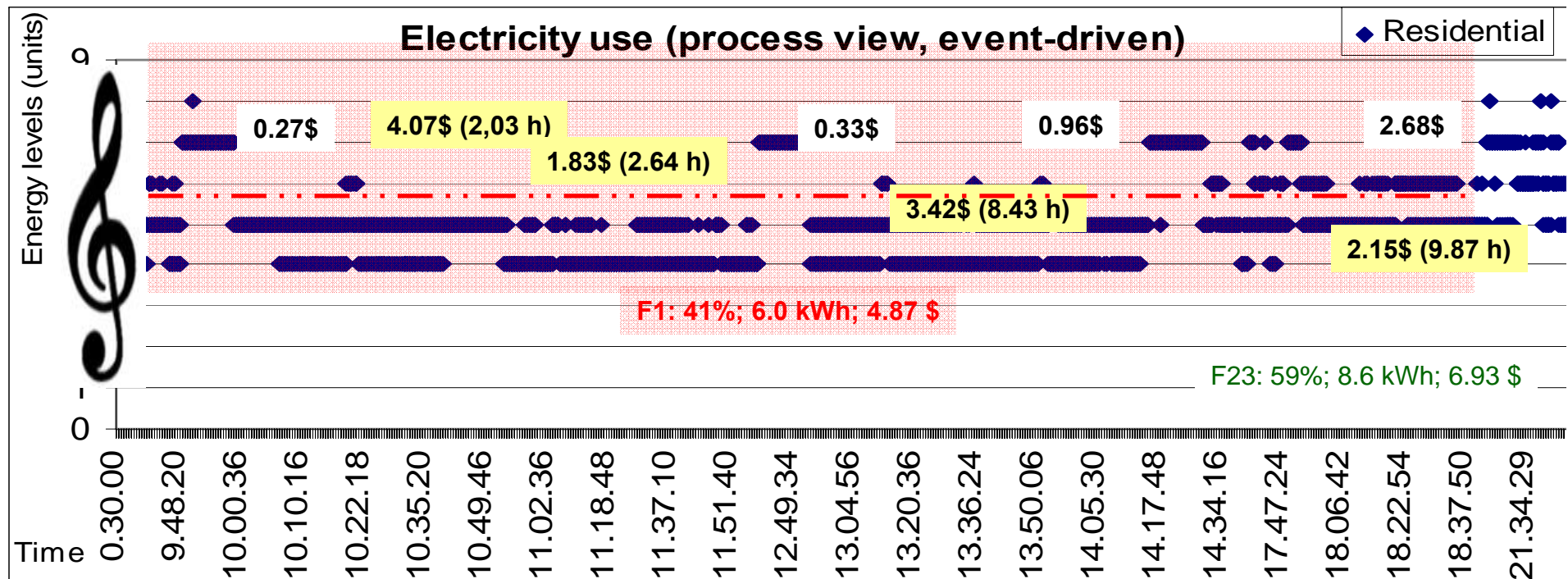


# Process-oriented billing by CMCA

The Electric Corp.

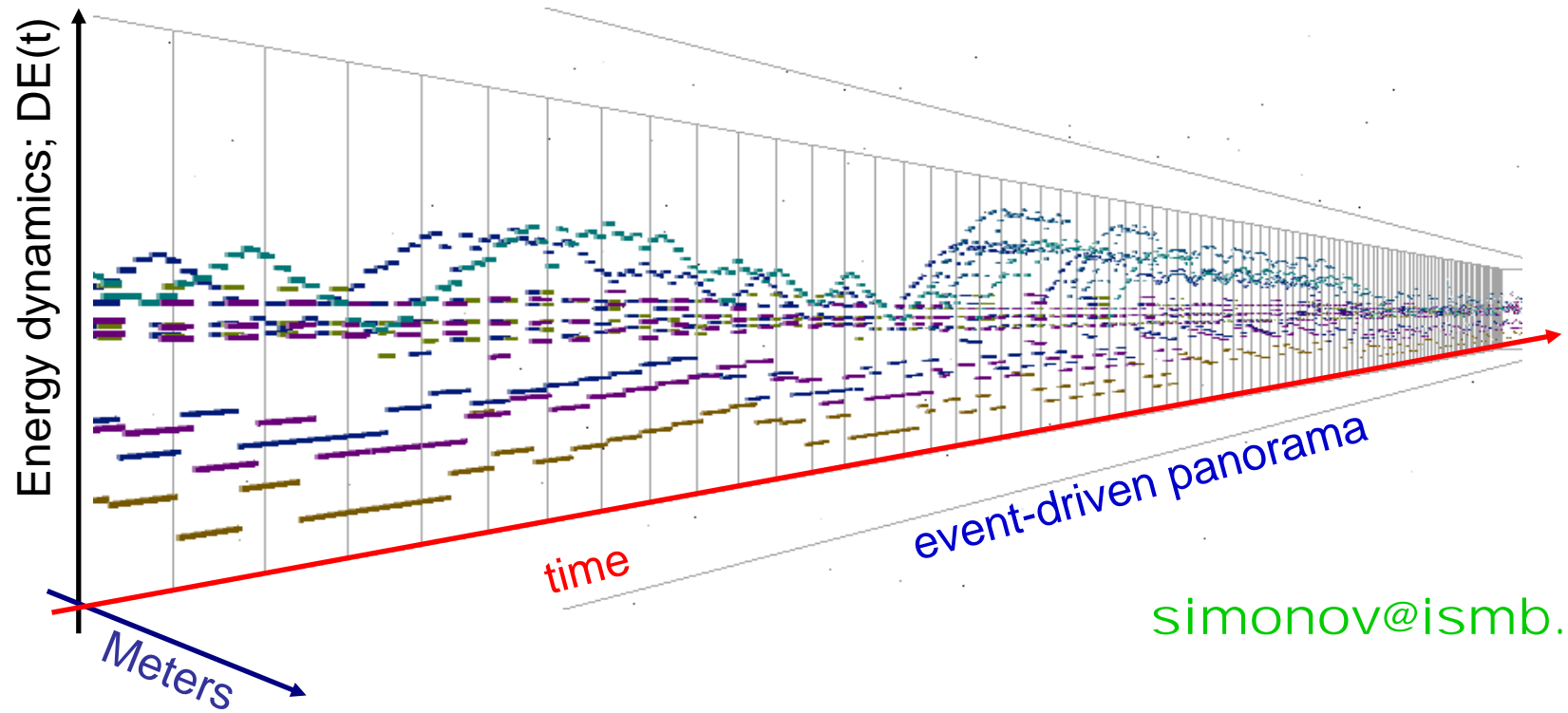
The Same Energy Bill (from 11/02/2011 to 12/02/2011)

Process view  
SOA/EDA  
compressed time





THANK YOU - TEŞEKKÜR EDERİM



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