An example based course curriculum for Performance Evaluation in Distributed Real Time Systems

Henrik Schiøler and Thomas Kølbæk Jespersen
Aalborg University
Denmark

WoNeCA 2018

AALBORG UNIVERSITY
DENMARK

Purpose

- Theoretical framework -> Engineering Community
  - user friendly tools
  - co-existence with other methodologies
    - Analysis vs Simulation
  - cooperation with other methodologies
    - Queueing theory vs Network Calculus
  - dissemination to the educational sector
    - Course curriculum for engineering
    - Cooperation projects with industry

Course Curriculum:
Distributed Real Time Systems

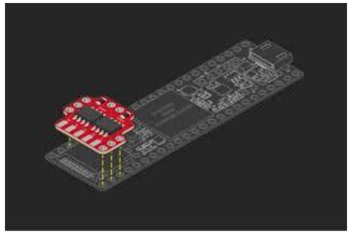
- Network Calculus
- Queueing theory
- Discrete event (stochastic) simulation
- (Reliability Modelling and Analysis)

- Mixed traffic on in-car network: Ethernet vs CANbus.

- RTC toolbox for MATLAB (ETH)
- CyNC toolbox for SimuLink
- OmNet++
- TrueTime for SimuLink. (Lund Uni)
- Mock-up network Arduino Teensy + FlexCAN library.

3 pillars:

- Analysis
- Simulation
- Experiments



DNC Curricula (AAU vs DISCO)

AALBORG UNIVERSITY
DENMARK

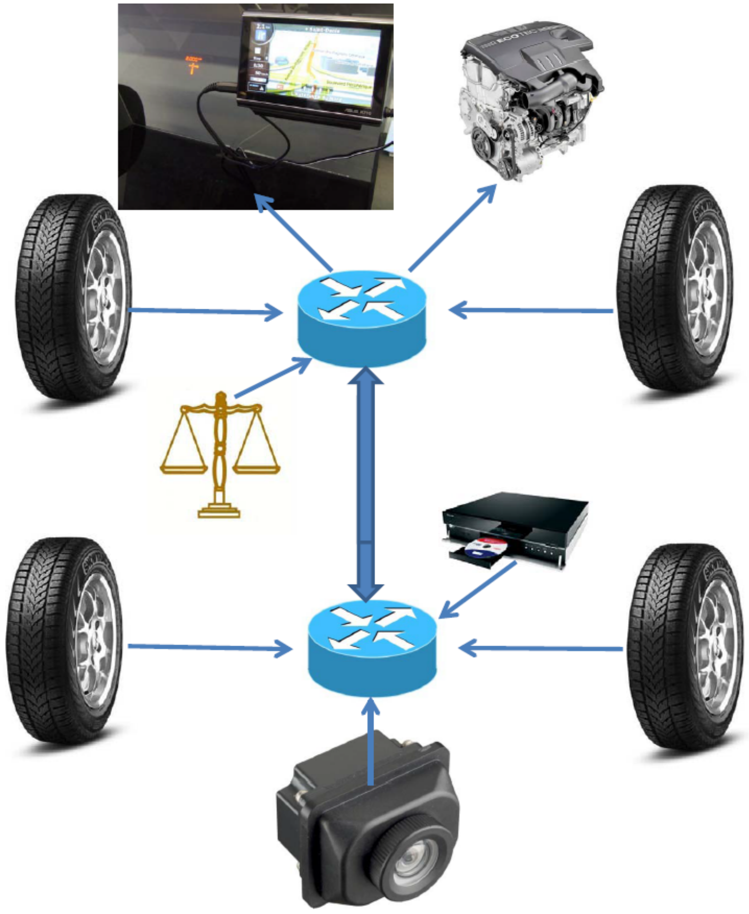
AAU

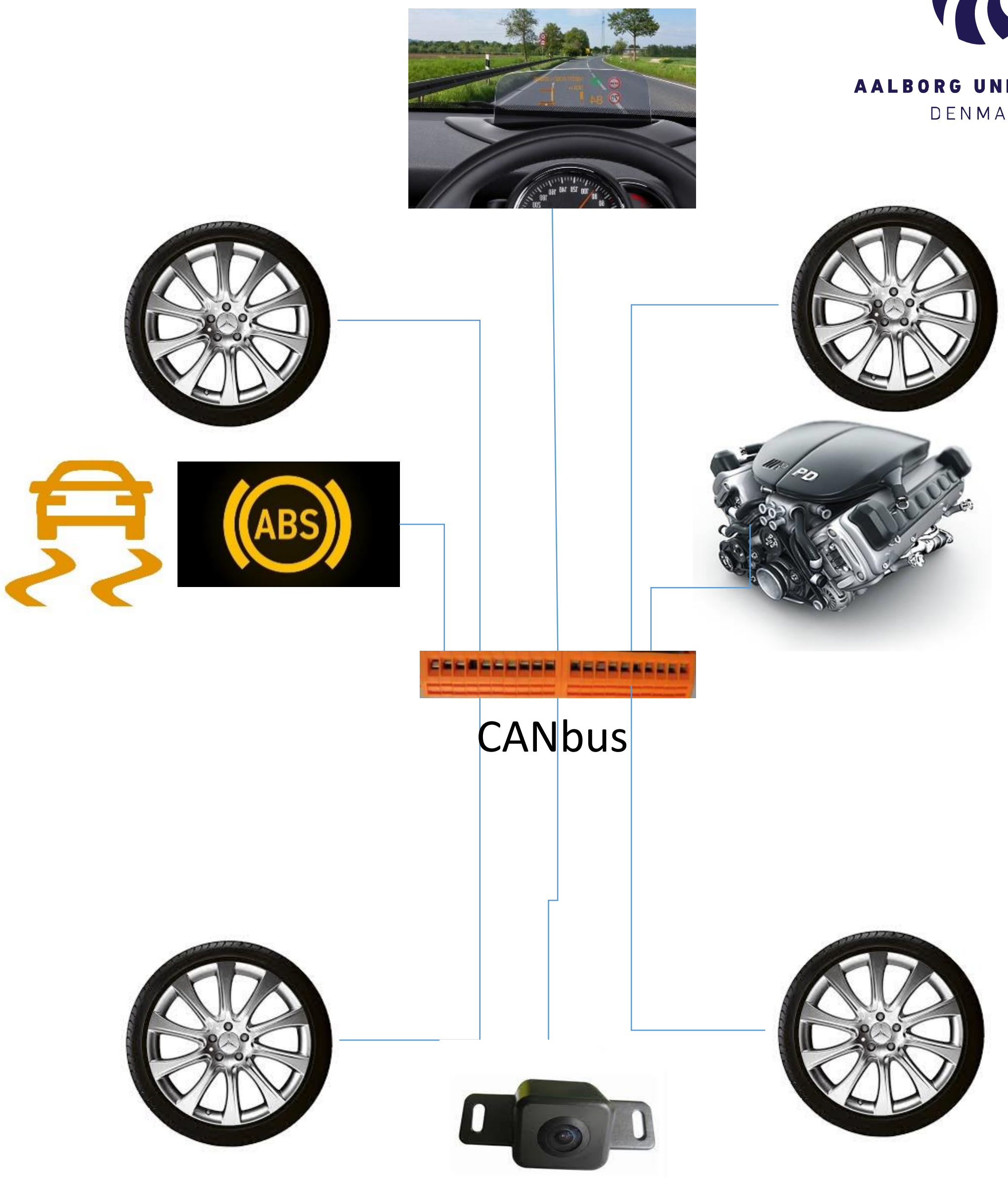
- Arrival curves: periodic (wj), spacing, affine, T-spec
- Service: Strict vs abstract, fluid, delay, rate-delay
- Theory: inf+, sup-,sub (super) additive closure
- Delay-, backlog-, output-bounds
- Prioritized ((non)pre-emptive) service.

DISCO

- MinPlusAlgebra
- Network Calculus Part I
- Network Calculus Part II
- Network Calculus Part III
- Timed Automata

Example Networks





AALBORG UNIVERSITY
DENMARK

Communication Pattern

Network elements

- 1MBps CANbus
- W{1,2,3,4}: wheel sensors measuring wheel position for ABS and EPS.
- EPS: Electronic Power Steering
- EC: Engine Controller
- HUD: Head Up Display
- MM: Multimedia system
- RC: Rear Camera

Transmission pattern

- W{1,2,3,4} -> ESP
- ESP -> EC
- MM -> HUD
- RC -> HUD

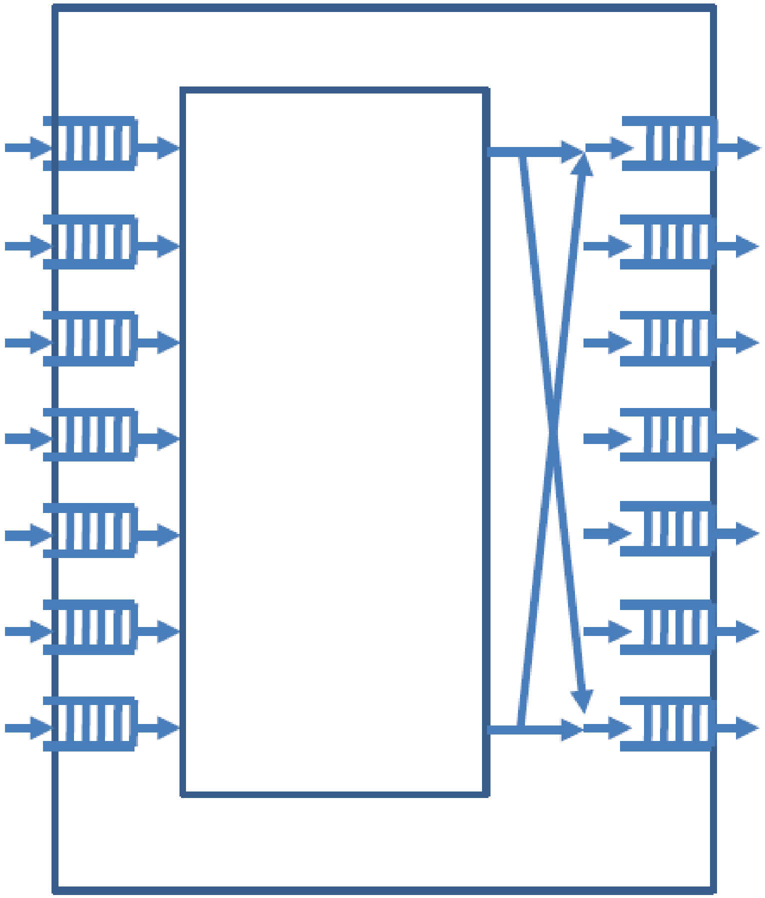
Traffic characteristics

AALBORG UNIVERSITY
DENMARK

Flow	Period / Mean period	Packet Size	Pattern
W(1-4)	10 mS	20B	Periodic
ESP	10 mS	8B	Periodic
RC	40 mS	1400B	Poisson
MM	40 mS	1400B	Poisson

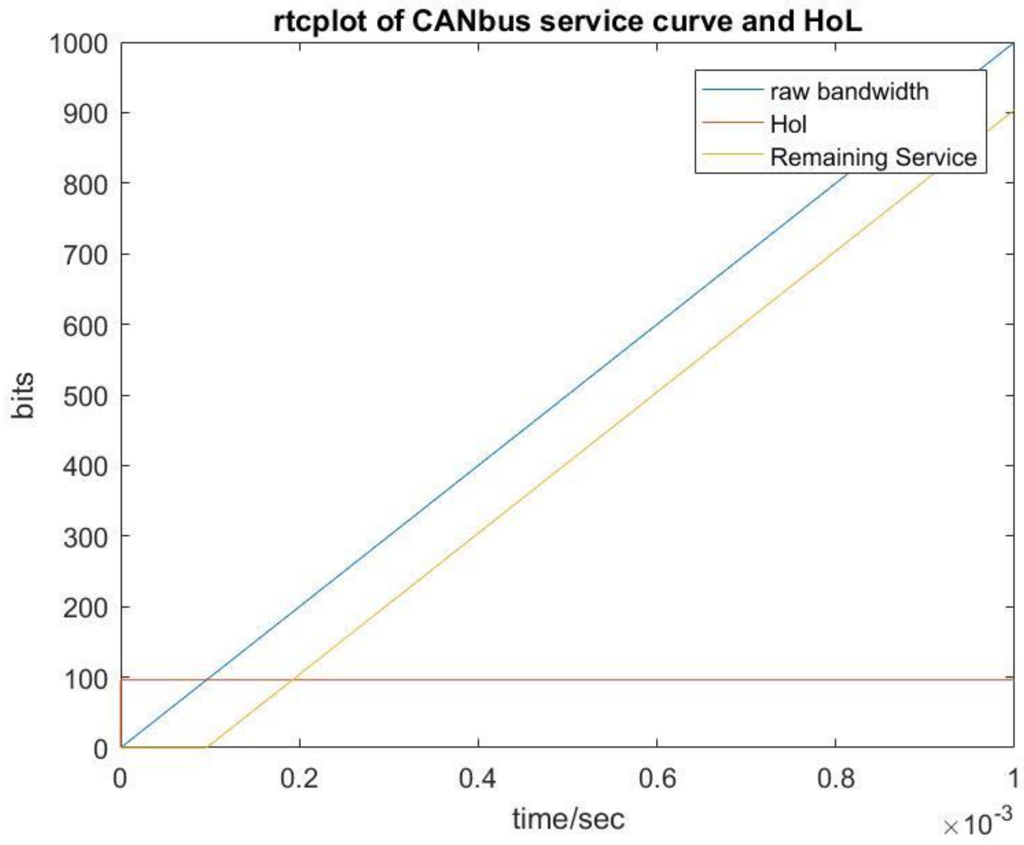
Ethernet Switch model

- Switch fabric is assumed infinitely fast
- Only store and forward delay in input queues
- When stored packets are moved instantly to output queues
- Queueing disciplines affect only output queues
- FIFO or FP scheduling

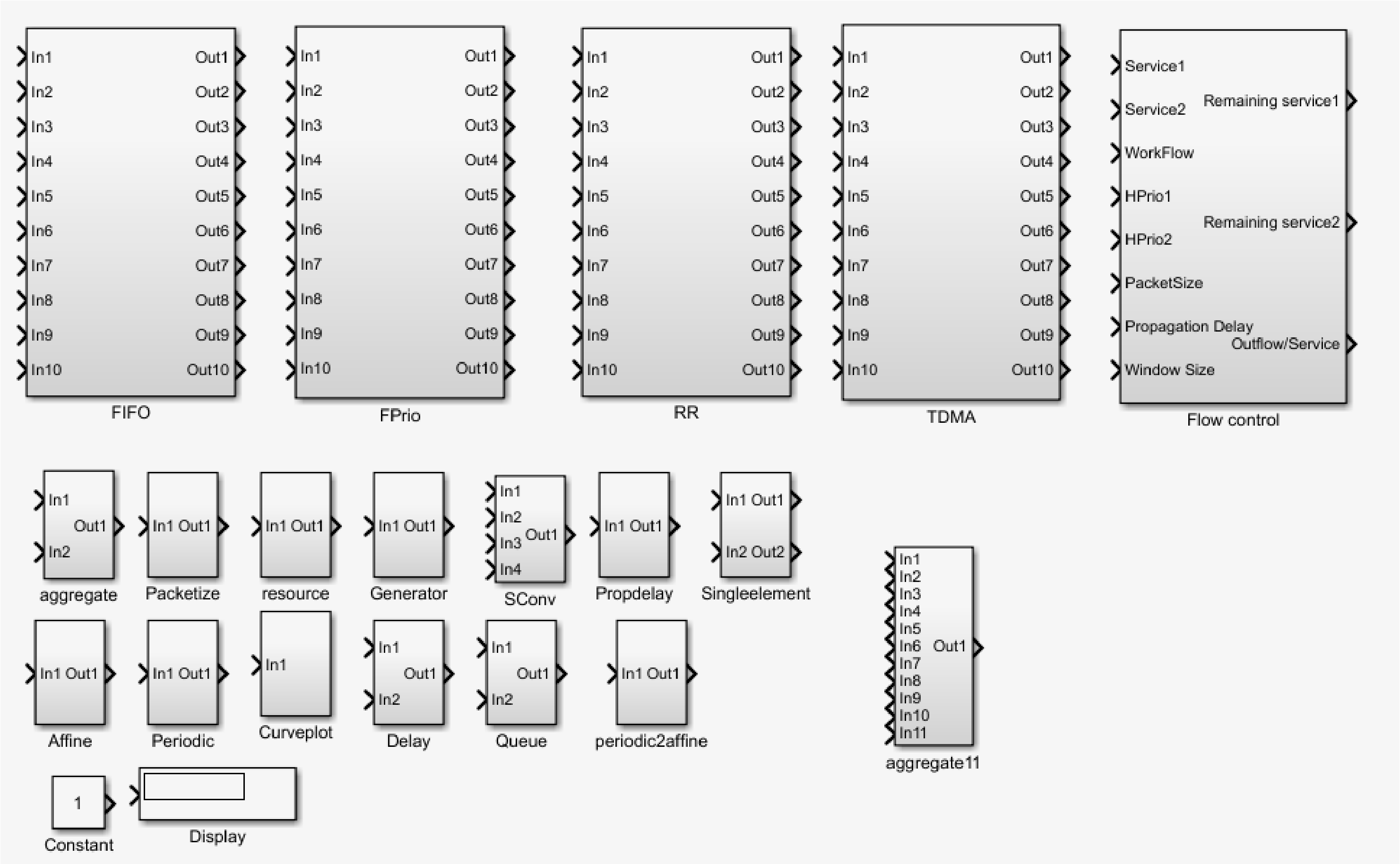


CANbus Model

- Bandwidth: 1Mbps
- CSMA/CA with prefix priority
- Non-preemptive Fixed Priority Scheduling
- Non-preemptive -> Head of Line Blocking (HoL)

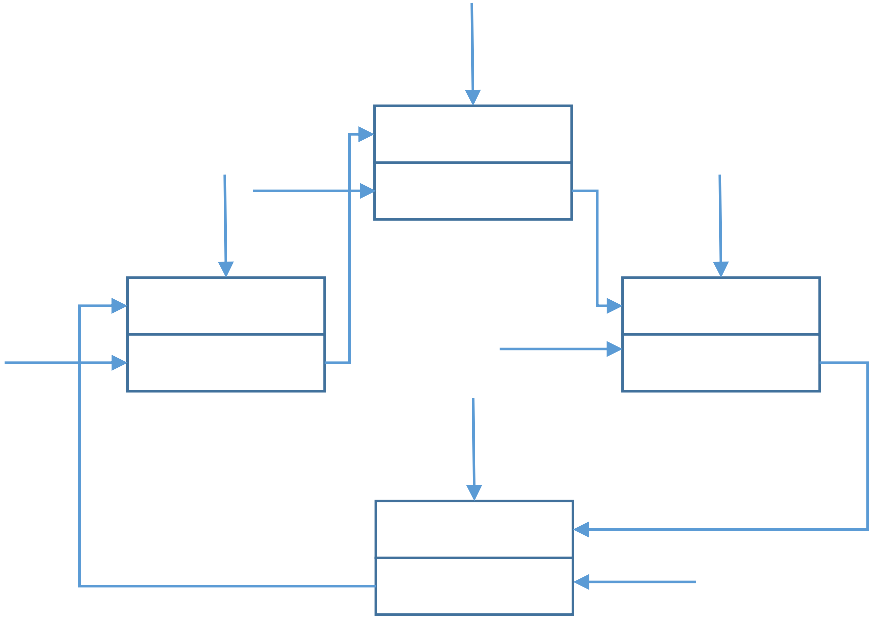


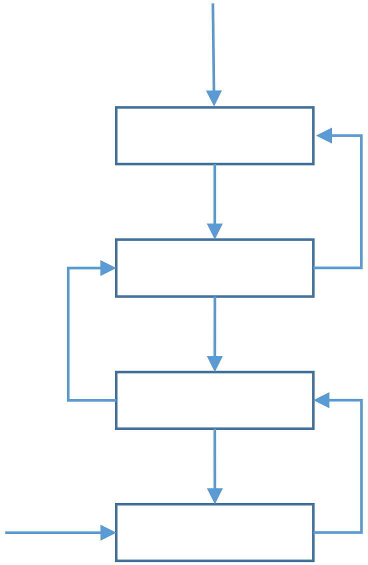
Cyclic Network Calculus (CyNC) a toolbox for MATLAB SimuLink



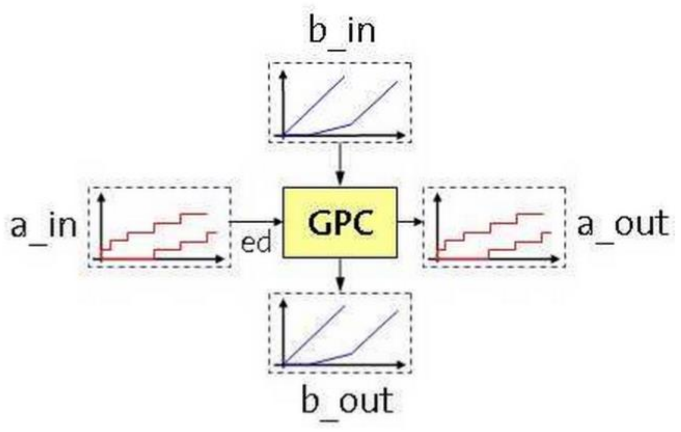
Cyclic Network Calculus (CyNC)

- Cyclic dependence
- Cyclic flow patterns
- Service/flow counter propagation

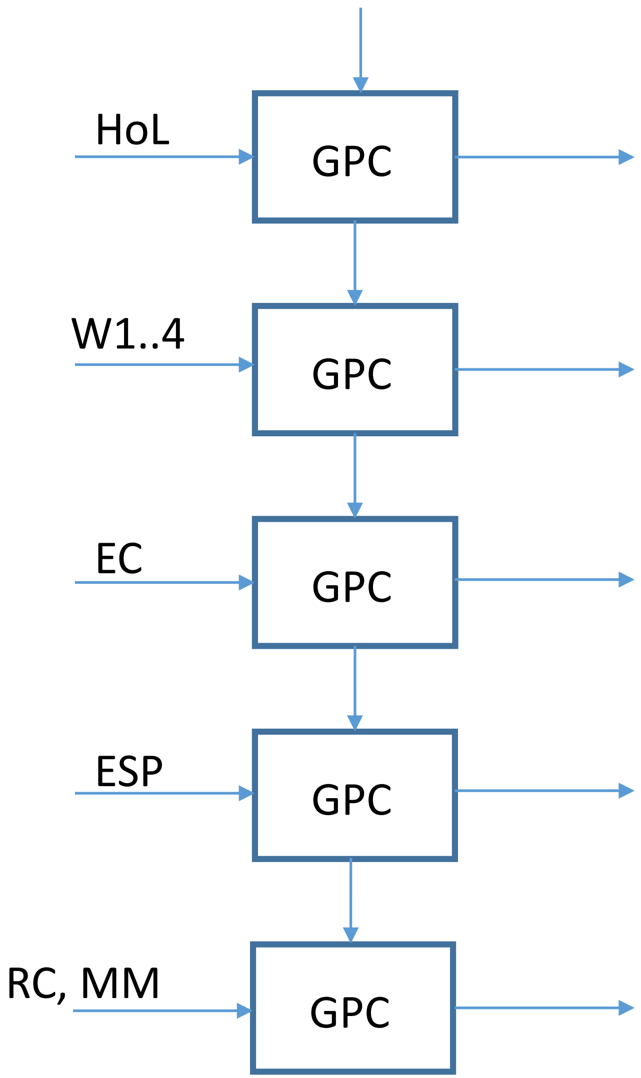


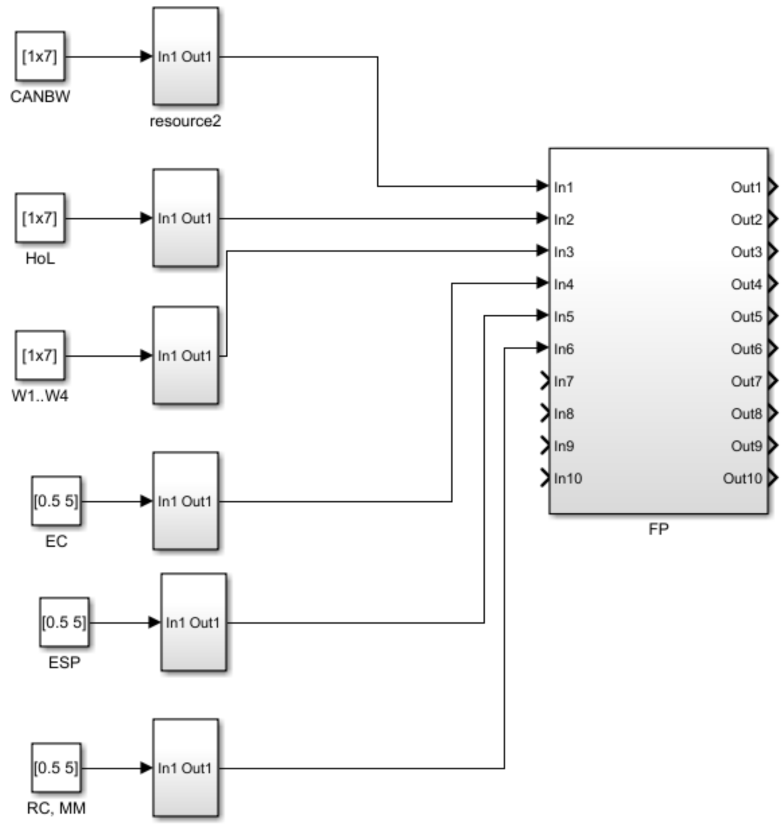


RTC/CyNC implementation of CANBus FP scheduling

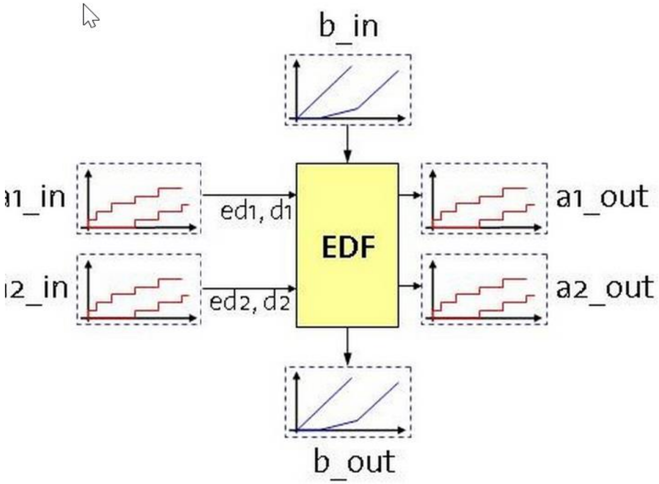



```
a_in = rtcpjd(3, 0, 0);
b_in = rtctdma(2, 7, 4);
ed = 3;
[a_out b_out del buf] = rtcgpc(a_in, b_in, ed);
```





RTC/CyNC implementation of EtherNet FIFO scheduling



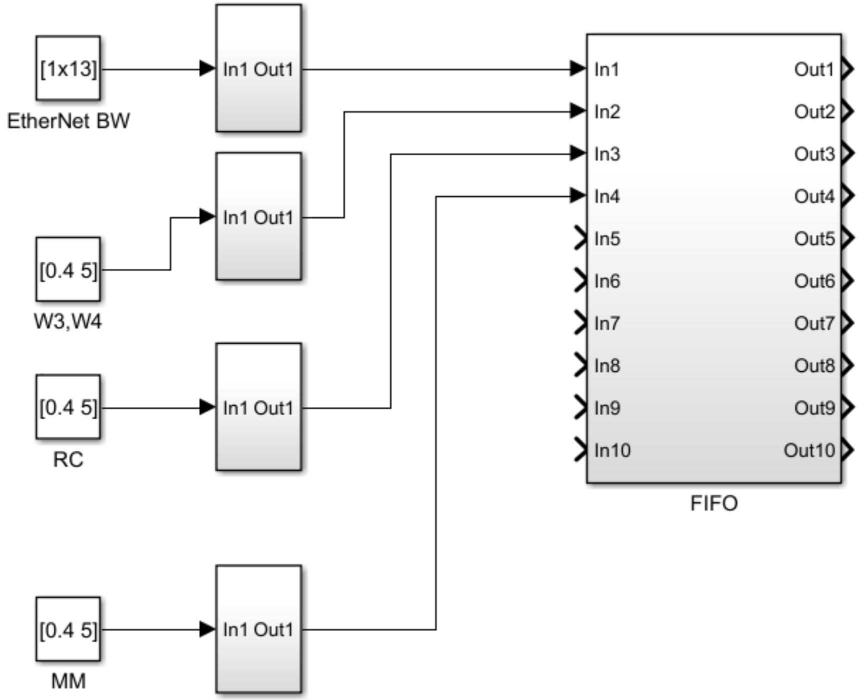
a1_in = rtcpjd(3, 0, 0); a2_in = rtcpjd(7, 0, 0);

b_in = rtctdma(3, 7, 4);

ed1 = 3; ed2 = 1;

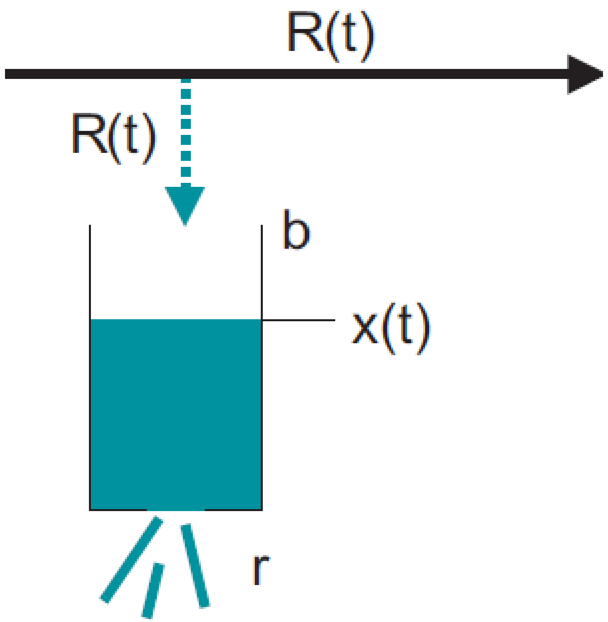
[a1_out del1 buf1 a2_out del2 buf2 b_out] = …

rtcfifo(a1_in, ed1, a2_in, ed2, b_in);



Aperiodic Streams MM and RC

- Modeled as Poisson arrivals !?
- Filtered through token/leaky buckets
- One token – one packet



Boudec: Netw. Calc.

Figure 1: The leaky bucket analogy

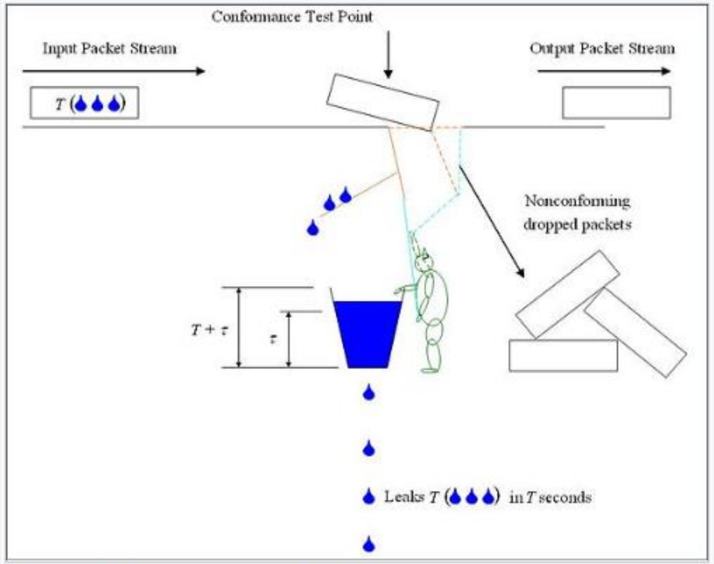


Figure 2: Traffic policing with a leaky bucket as a meter

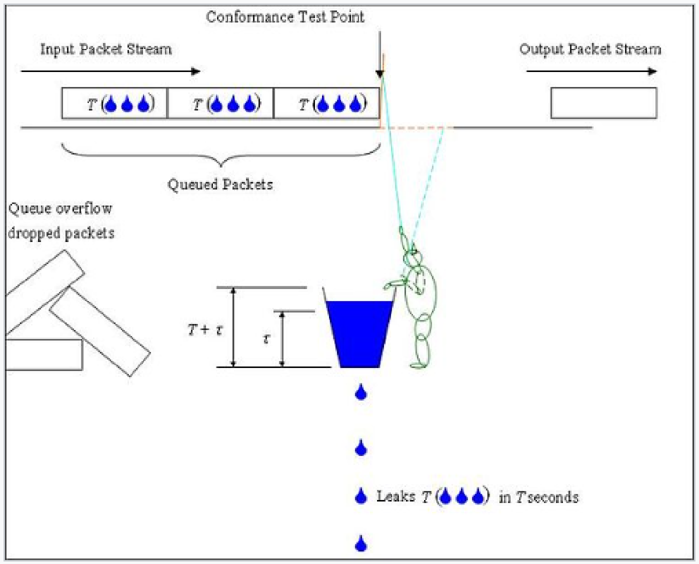
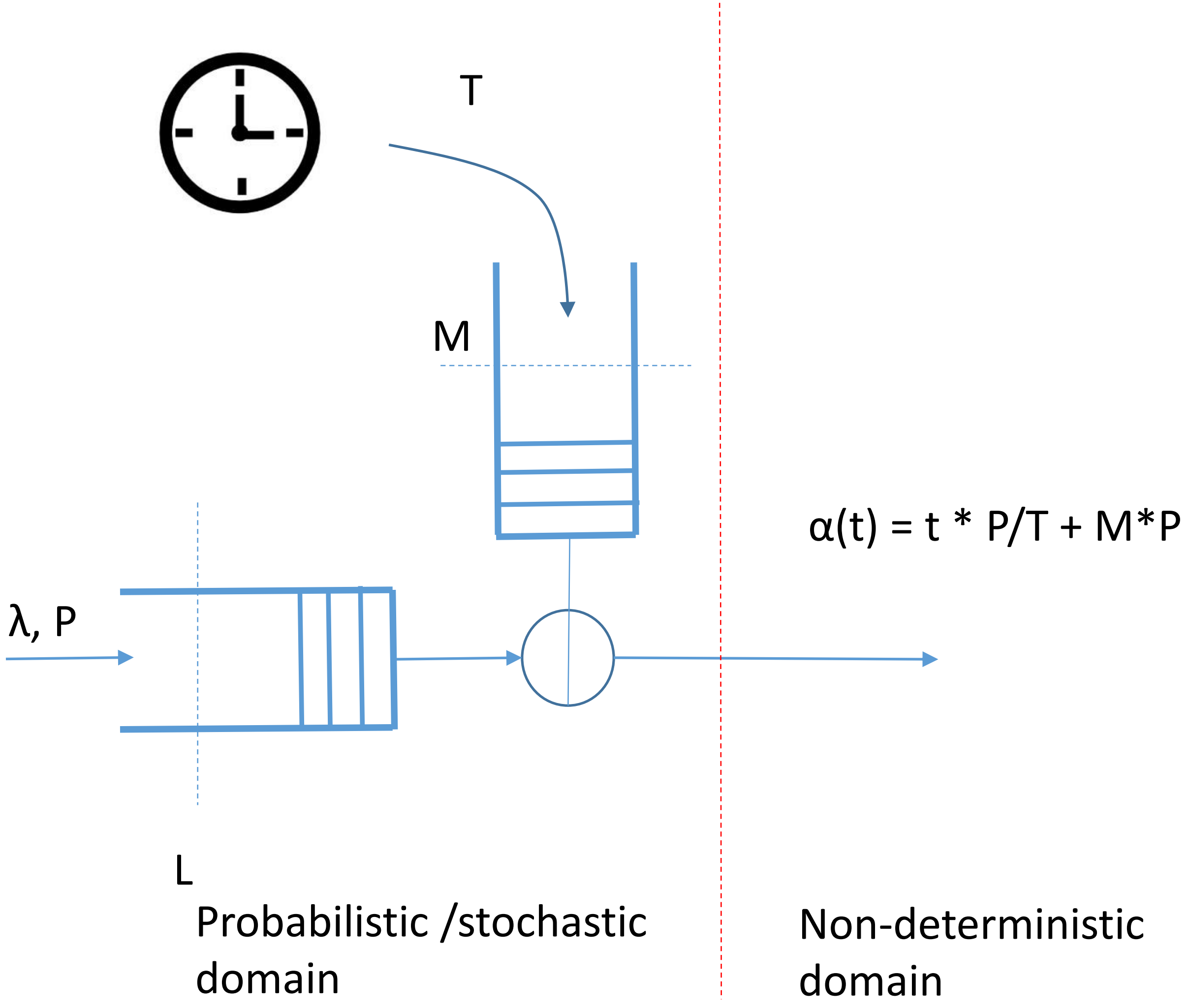
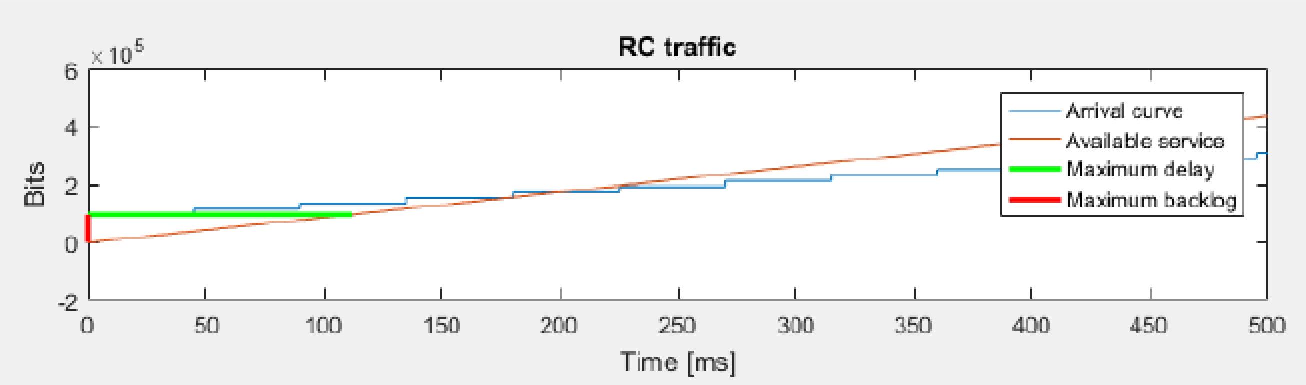


Figure 3: Traffic shaping with a leaky bucket as a meter

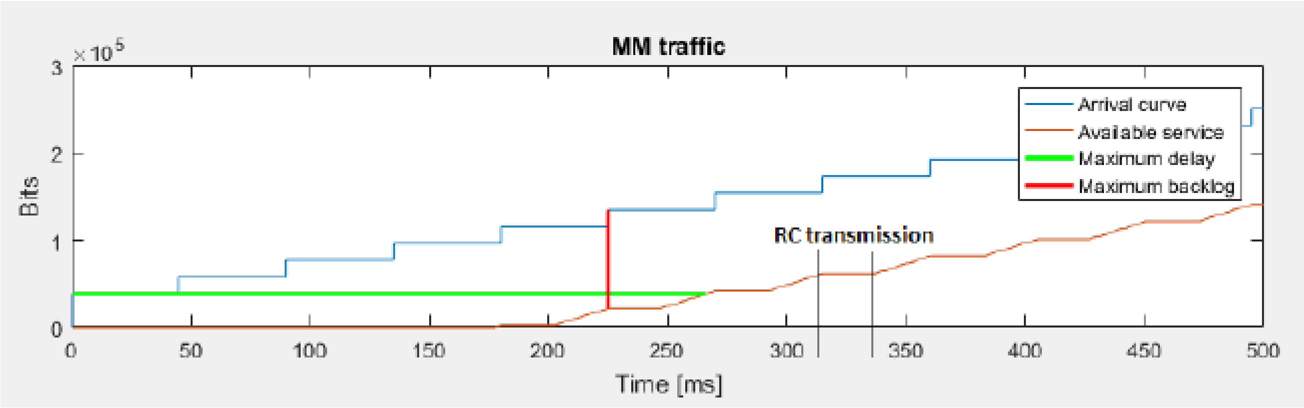
Separation of Domains



Delays and Backlogs



$d_{RC} = 111{,}984\ ms$
$backlog_{RC} = 5 \cdot P = 96250$



$d_{MM} = 266{,}2640\ ms$
$backlog_{MM} = 113056$
$> 2 \cdot \mathrm{P} = 38500$

Probabilistic Analysis

- Mean backlogs
- Mean waiting times
- Packet loss probabilities
- M/M/1/L+M queueing system with *warping*
  - Erlang B formula: $\pi_n = (\lambda T)^n / (n\,!\,(\Sigma_i\,(\lambda T)^i / i!)$
  - $P_{loss} = \pi_{L+M}$
- Discrete Time embedded Markov chain with *warping*

Discrete Time Embedded Markov Chain for Periodic Transfer

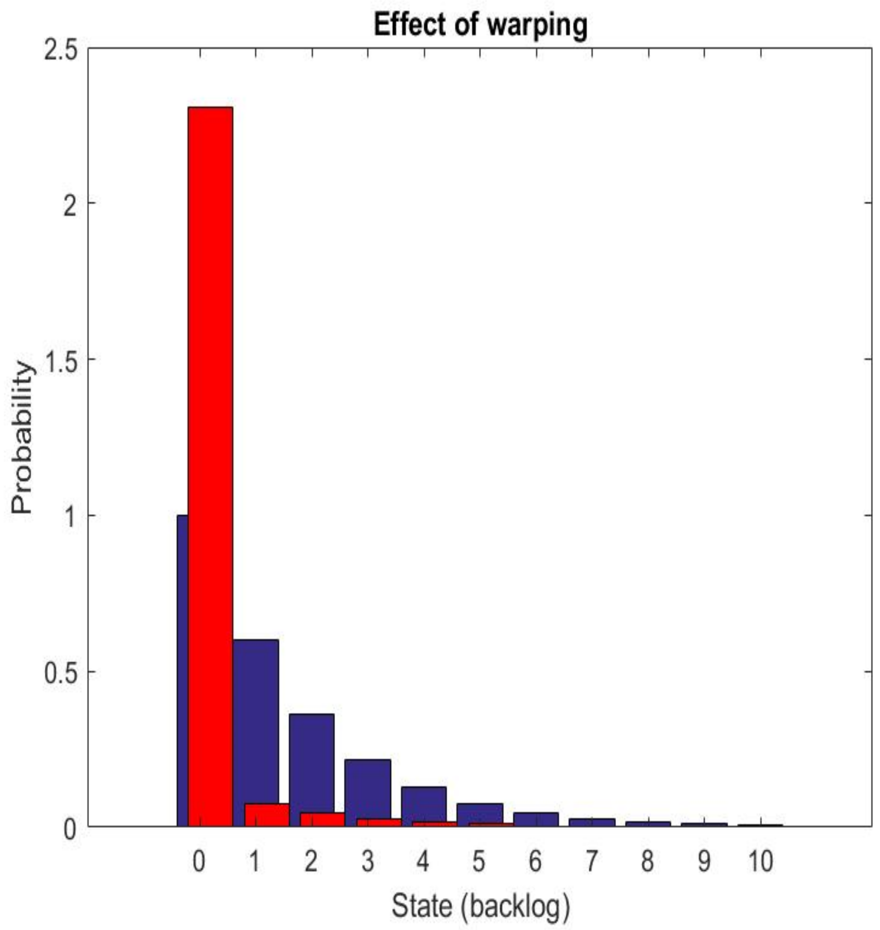
AALBORG UNIVERSITY
DENMARK

$$H = \begin{bmatrix} A_0 + A_1 & A_2 & A_3 & A_4 & \cdots & \cdots & A_{L+M} & 1 - (A_0 + A_1 + \cdots + A_{L+M}) \\ A_0 & A_1 & A_2 & A_3 & \cdots & \cdots & A_{L+M-1} & 1 - (A_0 + A_1 + \cdots + A_{L+M-1}) \\ 0 & A_0 & A_1 & A_2 & A_3 & \cdots & A_{L+M-2} & 1 - (A_0 + A_1 + \cdots + A_{L+M-2}) \\ 0 & 0 & A_0 & A_1 & A_2 & \cdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \cdots & A_0 & 1 - A_0 \end{bmatrix}$$

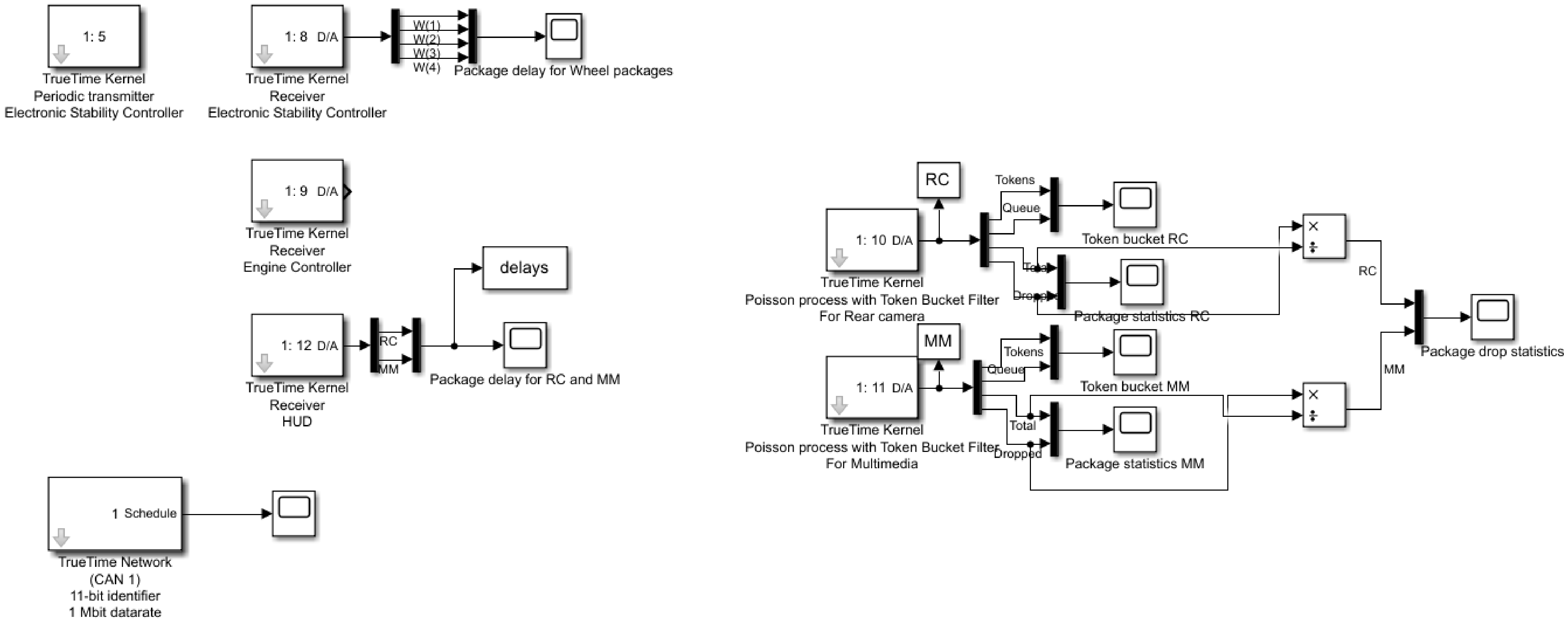
Probabilistic Analysis Warping

- $\pi'_0 = \pi_0 + \pi_1 + .. + \pi_M$
- $\pi'_n = \pi_{n+M}$
- $P_{loss} = \pi_{L+M} = \pi'_L$
- $Q = \Sigma_i \; i \, \pi'_i$
- $W = (1 - P_{loss}) Q / \lambda$

- P_{loss} depends only on L+M
- Higher L more waiting less M (burst)
- Lower L less waiting higher M (burst)



Simulation with TrueTime



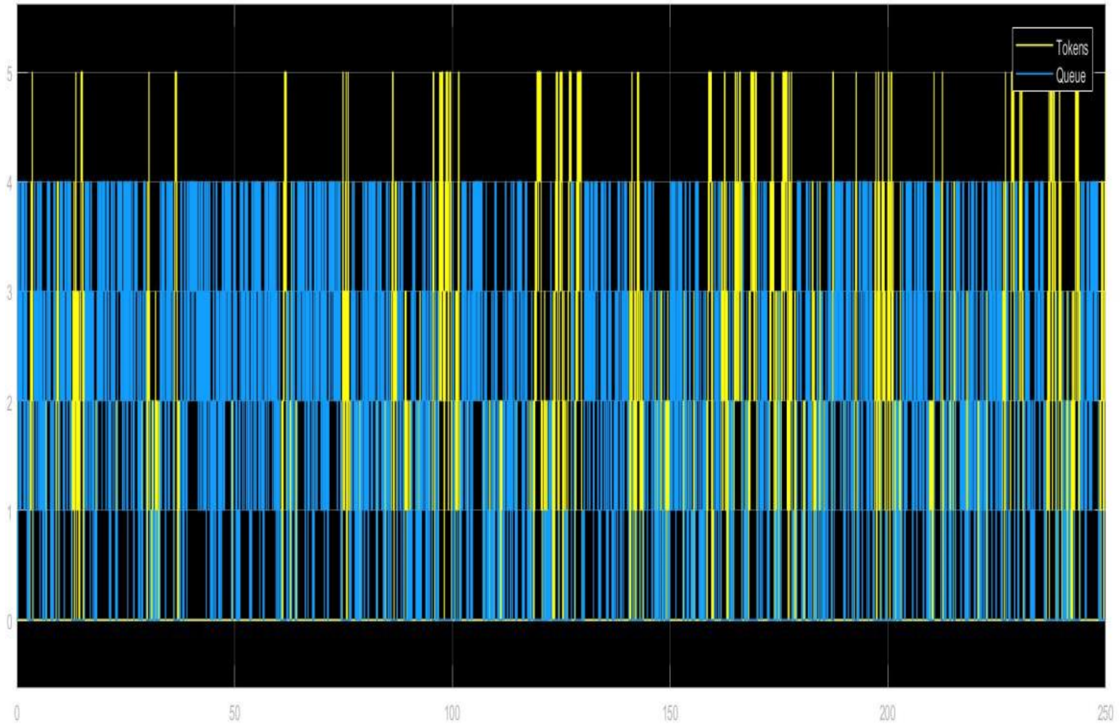
The TT kernel

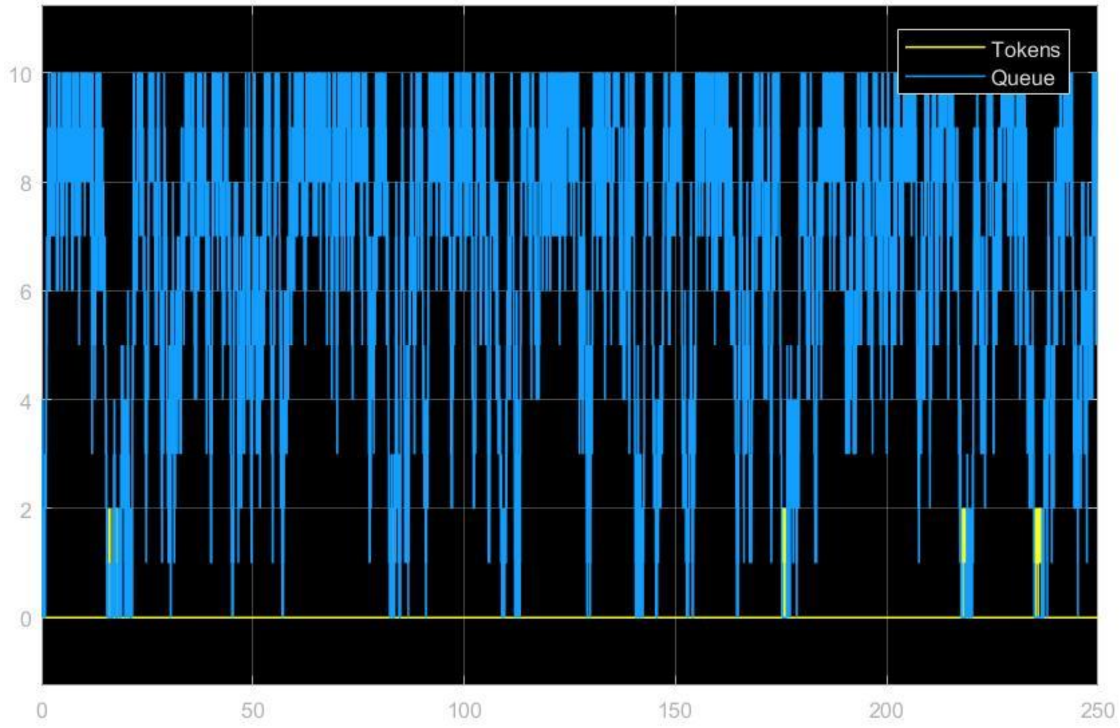
```
function generator_init

% Initialize TrueTime kernel
ttInitKernel('prioFP');  % scheduling policy - fixed priority

starttime = 0.0;
% Poisson generator task
ttCreateTask(‘generator_task', starttime, ‘generator_code');
%First job
ttCreateJob('generator_task', ttCurrentTime)
```

The TT task

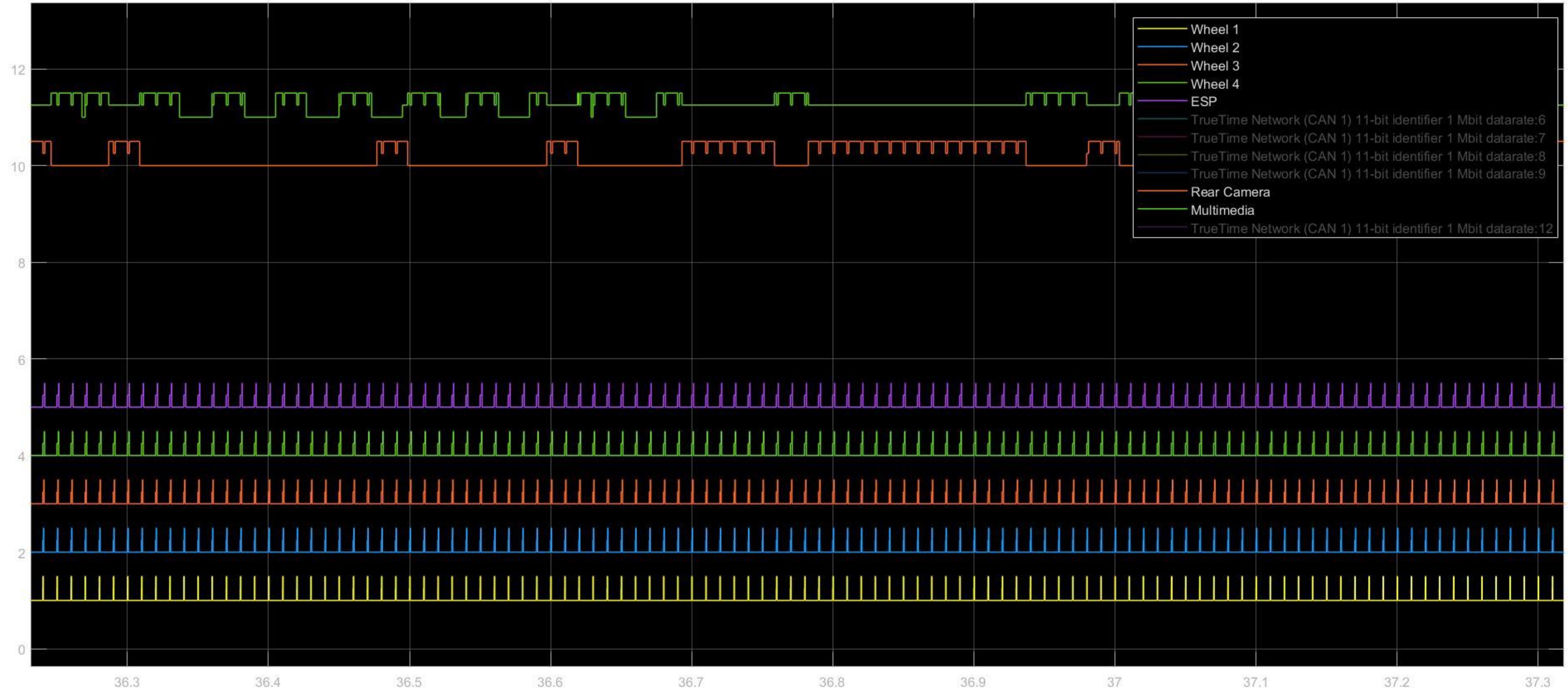
```
function [exectime, data] = generator_code(seg)

%independent exponentially distributed inter arrival time
lambda=10;   %intensity parameter
u=rand();
T=-log(1-u)/lambda;  %inverse fct method

%Send message on CANbus interface with highest priority to node ID 4
priority = 0;
msg = [ttCurrentTime];                    % message with timestamp for E2E delay statistics
ttSendMsg([14], msg, 250, priority);

%order next transmission
ttCreateJob('generator_task',ttCurrentTime+T)
exectime = -1;   %job done no CPU resources used
```

TT Backlog and Tokens

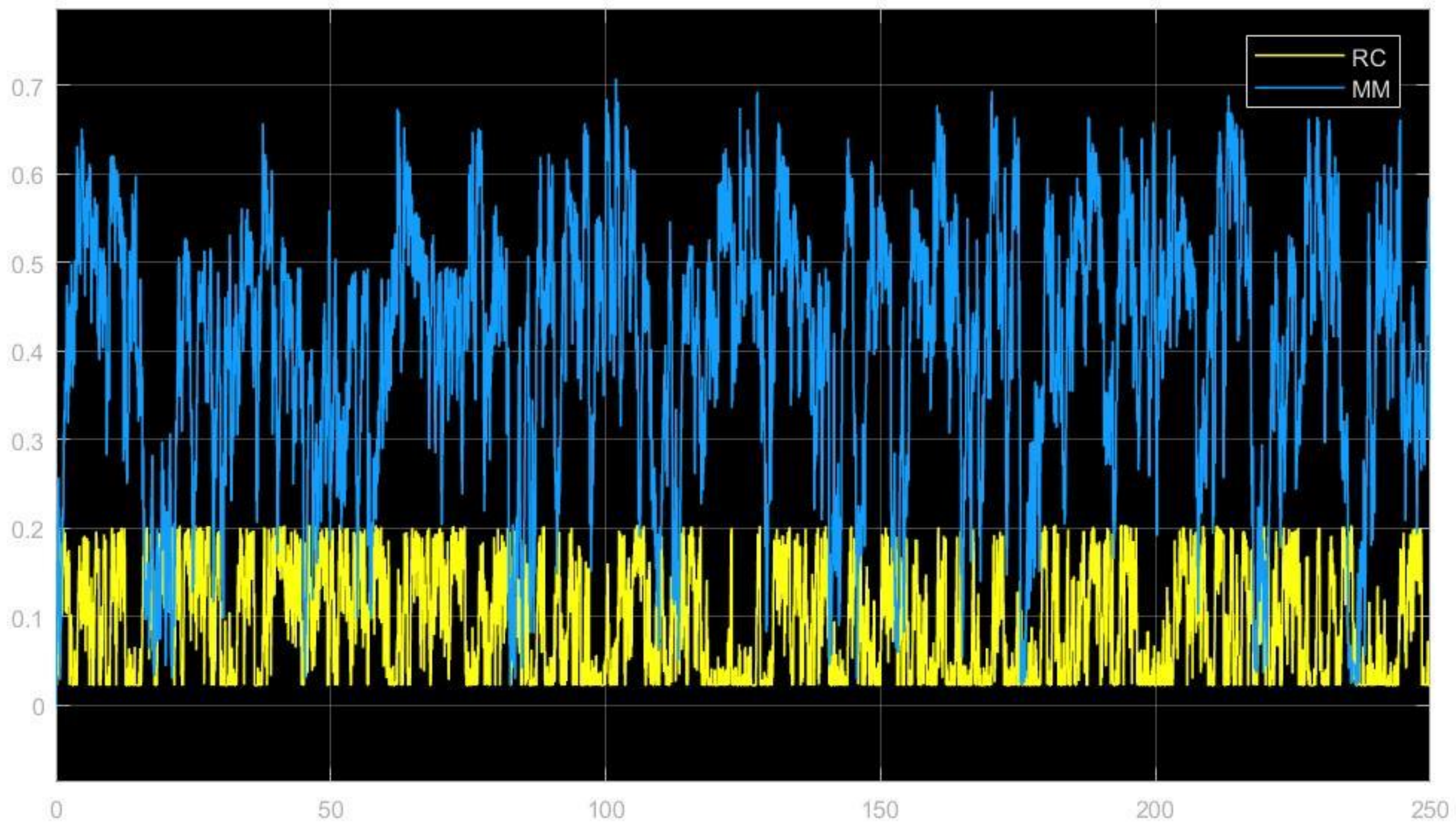




TT CANbus Network Schedules



TT E2E delays



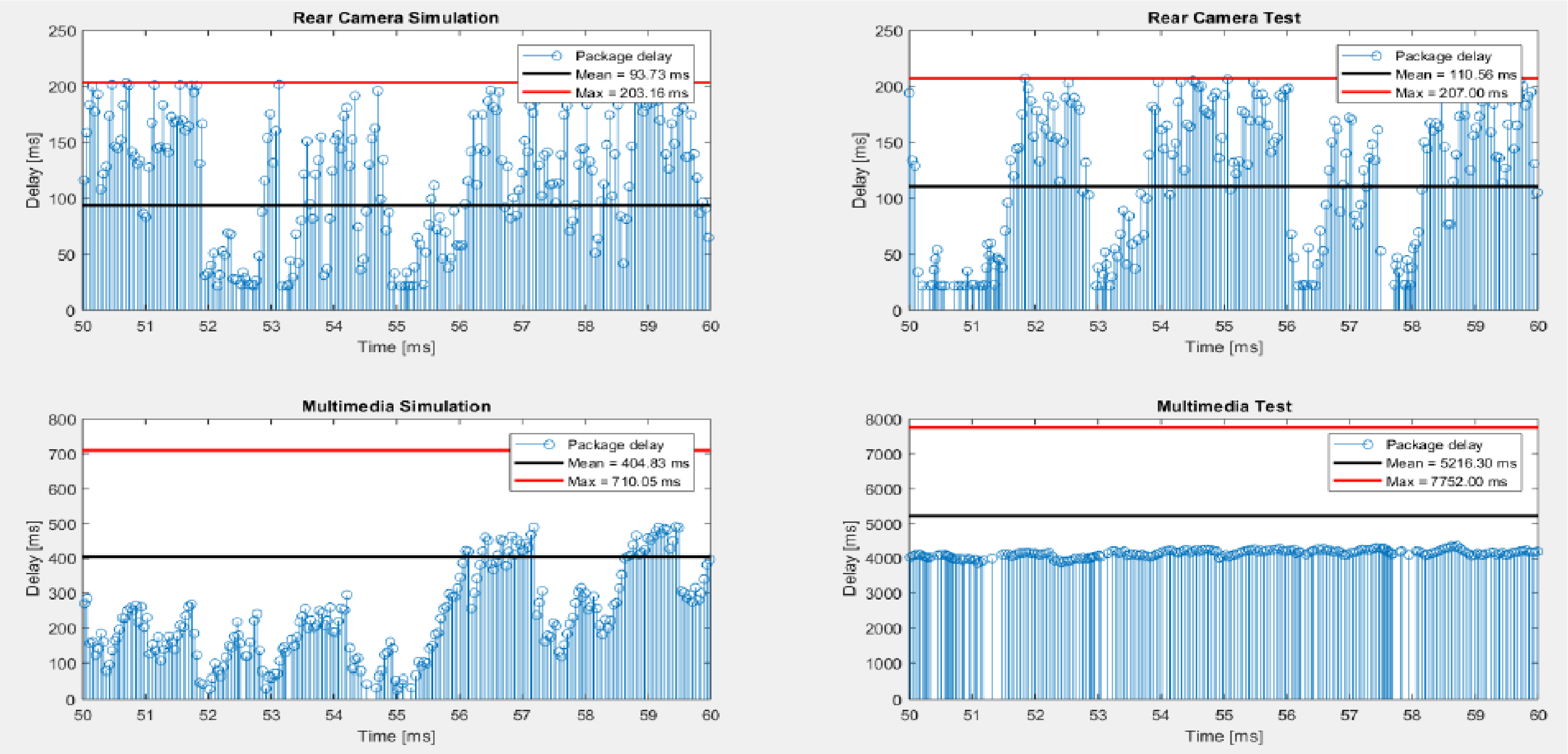
CANbus Test Delays

Delay

The mean package delays from the M/P/1 queueing model were calculated to:

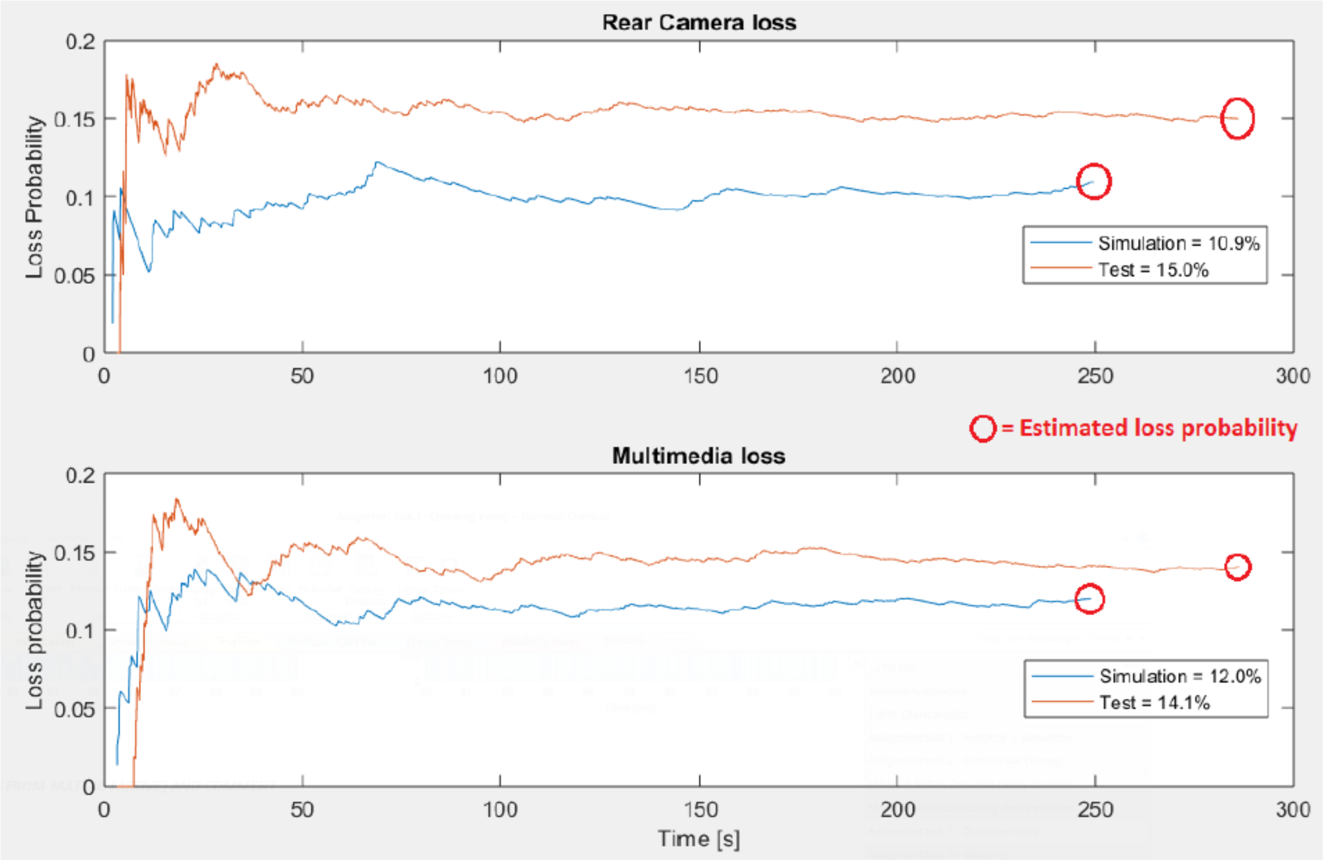
$\bar{W}_{RC} = 98.3\ ms$

$\bar{W}_{MM} = 356.8\ ms$



Loss Probabilities

The loss probabilities from the M/P/1 queueing model were calculated to:
$\Pi_{L_{RC}} = 23.31\%$
$\Pi_{L_{MM}} = 22.27\%$



CANbus Delays - MM