WMG THE UNIVERSITY OF WARWICK JAGUAR LAND ROVER

A SIMULATION BASED **ANALYSIS OF PRIORITY ALLOCATION STRATEGIES** UTILISING 802.1Q **FOR IN-VEHICLE NETWORKING SYSTEMS**

IEEE Standards Association (IEEE-SA) Ethernet & IP @ Automotive Technology Day
10th October 2018 presented by Mx. Liz James

INCREASING HARDWARE CAPABILITY
THE MOVE TOWARD CENTRALISATION

Driving Factors

1. Developing distributed systems of systems is hard
2. New and more powerful ECUs are arriving on the market regularly
3. Variety of factors make complex and 'many' component products undesirable

Consolidation of many low powered ECUs into more capable ones == Centralisation

Challenges

At the limit of centralisation:

1. Redundancy becomes highly cost ineffective (full duplication of systems)
2. Presents a single attack vector or point of failure
3. A Monolithic codebase becomes increasingly likely

Alternative

A software platform/API/SOA that hides many of the distributed components from developers:

1. Provides efficient abstraction for communication between networked components
2. Utilises a single API across every platform, easing development

HARDWARE ABSTRACTION AND SERVICE ORIENTATION
DYNAMIC SOFTWARE ARCHITECTURES

AUTOSAR Classic - provides tools allowing for hardware independent code to be developed.

AUTOSAR Adaptive Platform – begins to look at Service Orientation and Remote API calls.

Trend toward developing software/services capable of exchanging functional information using a set of standardised contracts/messages. (SOME/IP)

Including a broad set of Quality of Service requirements in these service contracts (such as in DDS) allows applications/middleware to change behaviours according to current operating conditions.

PROJECT AGENDA

SIMULATING NEXT GENERATION VEHICULAR ARCHITECTURES

- The project looks to explore *how* one might utilise the QoS/shaping/metering and management tools present in a 'Next Generation' vehicular network architecture utilising Ethernet, to meet the demands of an automotive use case.

- No 'Next Generation' vehicular network architecture utilising Ethernet exists today, the work aims to assist in the development of such an architecture.

- The development of a simulation of such a 'Next Generation' architecture was chosen to bypass many of the inherent challenges associated with cutting edge hardware and software development.

- This presentation will covers some of the details of the approach and provide some insight into the preliminary analysis

PROBLEM DEFINITION

A distributed system of systems needs to be able to exchange information efficiently.

If nodes in such a system have:

- The Quality of Service requirements of applications dependent upon it
- The ability to assign parameters that change how the network treats each message

The question becomes:
How and when should we decide what behaviour for nodes to employ?

- Compile time
- Configuration time
- Run time

And which is best? What advantages and disadvantages are there to each approach?

ACHIEVING QUALITY OF SERVICE REQUIREMENTS
SELF TUNING OR NETWORK CONFIGURATION?

The performance of a set of distributed applications is dependent upon the configuration of the network and on the behaviour of the applications.

Fixed: Application Behaviour, Optimise: Bridge/Switch Configuration

- Looks at how network bridges' configurations can be assigned, given applications whose interactions with the network are constrained/defined or static.

Fixed: Bridge/Switch Configuration, Optimise: Application Behaviour

- This presentation focuses on providing distributed application models the ability to vary their 802.1Q tagged parameters in order to achieve their QoS requirements.

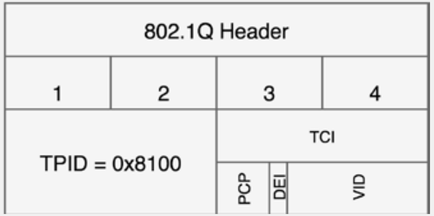
TIME SENSITIVE NETWORKING & 802.1Q

WHAT BITS OF 802.1Q?

IEEE P802.1Q-REV/D2.2 brings over 2000 pages of operating principles, algorithms, protocols and management systems for Media Access Control (MAC) for bridged Ethernet networks.

This project:

- Utilises Ethernet bridges with egress queues configured using:
  - 802.1Qav – Credit-based Shaper Algorithm
  - 802.1Qbv – Time Aware Scheduler
- Assumes network component time-synchronisation as per 802.1AS
- Provides a variety of link segments as specified by 802.3bw (100Mbps), 802.3bp (1Gbps), 802.3ch[*] (2.5Gbps, 5Gbps, 10Gbps)
- Includes a 10Mbps mixing segment (similar to 802.3cg[†]) that employs TDMA



An 802.1Q Tag is made up of:

- Tag Protocol Identifier – TPID (16bit)
- Tag Control Information – TCI (16bit)
  - Priority Code Point – PCP (3bit)
  - Drop Eligible Indicator – DEI (1bit)
  - VLAN Identifier – VID (12bit)

And allows bridges to identify what egress queues to assign inbound frames to (amongst other things)

[*] Pre-standard, extracted from Multi-Gig Automotive Ethernet PHY Task Force Objectives

[†] Pre-standard, extracted from 10Mb/s Single Pair Ethernet Task Force Objectives, MAC using TDMA assumed due to automotive requirements

ACHIEVING QUALITY OF SERVICE REQUIREMENTS

APPLICATION QUALITY OF SERVICE REQUIREMENTS

- Timescales for Application developers:
  - 10^{-4}s – 0.0001s – Highest priority control signals such as “by-wire”
  - 10^{-3}s – 0.001s – Decision making, complex sensor data acquisition etc.
  - 10^{-1}s – 0.1s – Non-critical user input and non-safety critical control.
  - 10^{0}s – 1s – Offline Diagnostics and everything else.

Frustratingly, the *safety-critical* applications are typically also *time-sensitive* (*-by-Wire) but not all *time-sensitive* applications are *safety-critical* (Audio streams).

One of the goals of an SOA in this situation is to provide abstraction between the hardware and software functionality such that developers need only minimal consideration of the hardware constraints to deliver their intended functionality.

MAPPING APPLICATION QOS TO TSN

MAKING PREDICTIONS

- Knowing, in advance, the transit time for an Ethernet frame, as a function of PCP/DEI, allows for decisions to be made about what values to assign to each parameter.

- Other approaches focus on calculating the upper bound of this network transit time. The problem is constrained in order to generate results for switches with drop-tail queues or congestion management.

- We are attempting to minimise the amount of constraints applied to the application behaviour opting instead to provide an error term calculated using scenarios/samples that experience these challenging behaviours.

- Both approaches are complementary and can be used to facilitate better allocation strategies.

PREDICTING NETWORK TRAVEL TIME

$$\boldsymbol{t_{E2E}}$$

The end-to-end travel time for an Ethernet frame can be broken down into the following parts:

$$t_{E2E} = \underbrace{t_{transmission} + t_{propgation}}_{} + \underbrace{t_{processing} + t_{queueing}}_{}$$

On a static network topology, this is pre-computable and can be implemented in a lookup table.

$t_{processing}$ is highly dependent upon manufacturer implementation. $t_{queuing}$ is highly dependent upon other application behaviour and network configuration.

$$t_{transmission} = \sum_{i}^{Hops} \frac{N_{bits}}{r_i}$$

$$t_{propagation} = \sum_{i}^{Hops} \frac{l_i}{c_i}$$

The challenge is making an accurate prediction of the configuration dependent variables per application.

Constructing a model of $t_{queueing}$ that takes into account compile-time, configuration-time and run-time parameters is the next step.

CONSTRUCTING NETWORK MODELS PREDICTING t_{E2E}

What information is available locally?

- Destination and Source MAC address
- Frame size
- Historical behaviours

What do we need to compute?

- Network travel time

What else can we gather?

- In a simulated environment
  - Queue Lengths
  - Other node behaviour
- Implementation

Regression

System State Analysis

- Regression Analysis (SVM, Ensemble)
- Artificial neural networks (ANNs)

Train/Calculate then assess error

Time Series Behaviour Analysis

- Long short-term memory (LSTM)
- Autoregressive integrated moving average (ARIMA)

MAPPING STRATEGIES UTILISING MODEL PREDICTION

Acting upon a prediction of $\mathrm{t_{E2E}}$ is important.

The prediction is highly dependent upon the other applications.

The error of the prediction, ϵ, needs to be considered for *safety critical* applications

Thus a variety of mechanisms for assigning the priority code point based around the prediction are presented and compared.

Random Assignment

- Randomly assign priority codes independently of Quality of Service requirements

Greedy Optimisation

- Minimise end-to-end travel time only
- $\mathrm{Min}(\mathrm{t_{E2E}} \pm \epsilon)$

Resource Minimisation

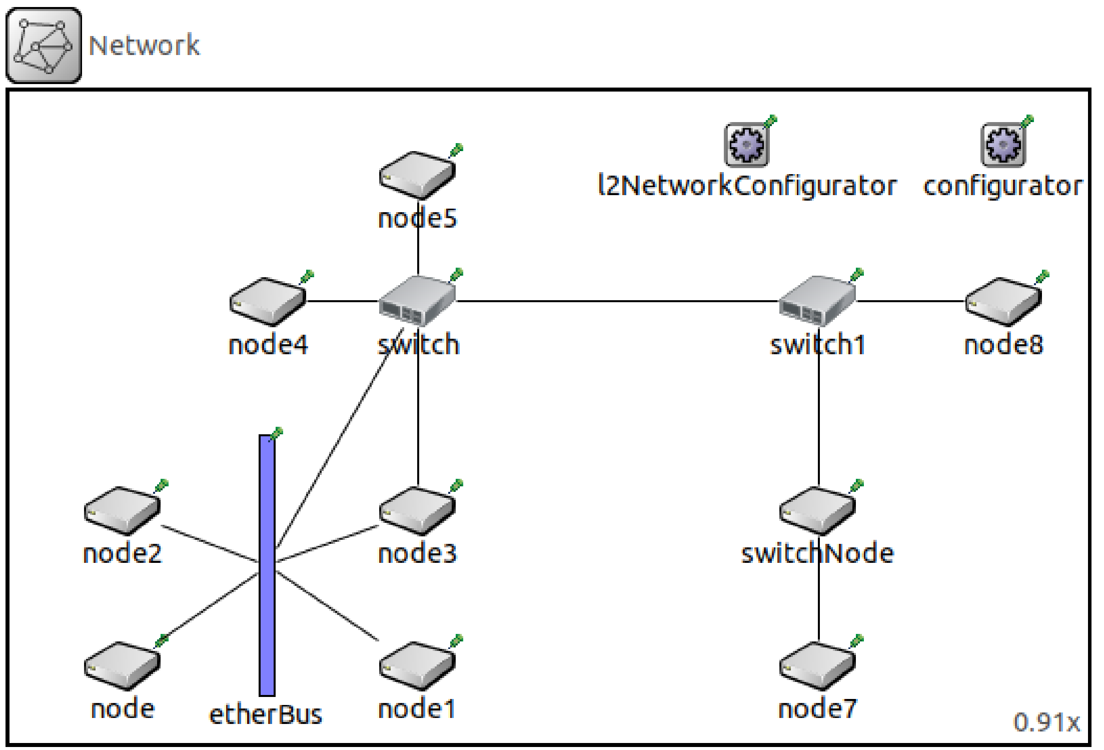
- Minimise the difference between the Quality of Service requirements and the End to End travel time without missing.
- $Min\left(t_{QOS} - (t_{E2E} \pm \epsilon) > 0\right)$

SIMULATED NETWORK TOPOLOGY

OMNET++ FRAMEWORK → INET → CUSTOM LIBRARIES

Key Points

- 10ms for the (Time-Aware Scheduler) Gate Control List cycle-time across entire network*.
- 10Mbit/s shared medium Ethernet using equi-allocated 10ms TDMA with 4 nodes†.
- Variety of link segment bit-rates.
- Node with integrated switch hardware.



* Each switch can be configured independently.

† Equal to switch GCL cycleTime but can be set independently.

SIMULATING NETWORK TRAFFIC - APPLICATION MODELS

ETHERNET TRAFFIC GENERATION MODELS FOR AUTOMOTIVE APPLICATIONS

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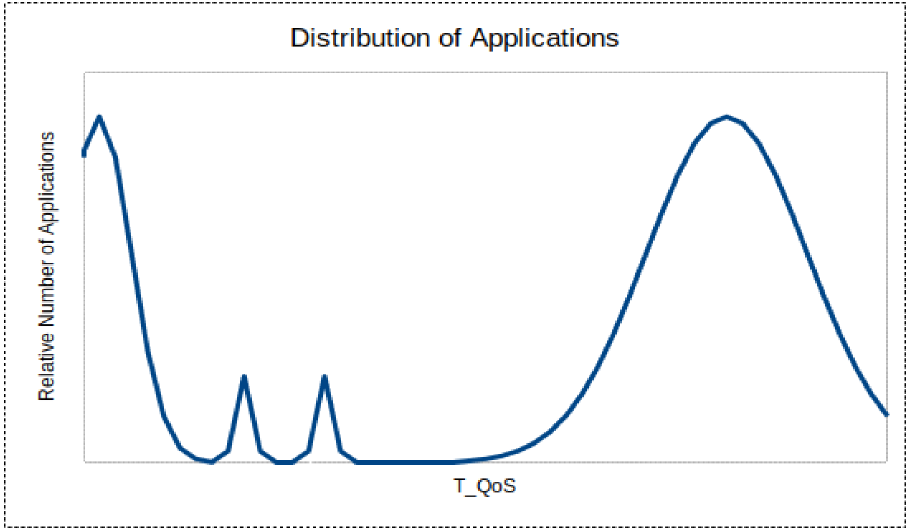
Application Model Types

- Constant Bitrate
  - These traffic models generate traffic at a frequency, *f,* of a size, L.
  - Used for modelling sensors such as cameras.
- Sporadic Signals
  - Applications that generate traffic of size, L, with an interval determined by a Gaussian or Poisson distribution between, t_min and t_max.
- Event Triggered
  - These applications generate traffic upon the receipt of an inbound message after some delay, t.

Application Distribution

- Why is the application distribution important?
  - Would like to learn from network behaviours that are closer to a system of systems rather than of traffic comprised of systems communicating randomly.



RESULTS AND ANALYSIS
INTERPRETING THE MODEL RESULTS

Training the models utilises the data collected from the simulated environment and is currently done once on the complete dataset (offline).

Future work aims to introduce reweighting and coefficient recalculation as parameter values are updated from the network (online).

Key points:

- Current key variables are: PCP and DEI.
- Exploring the entire configuration space is a significant computational task.
- Preliminary analysis aims to explore Ethernet frame and Topological parameters

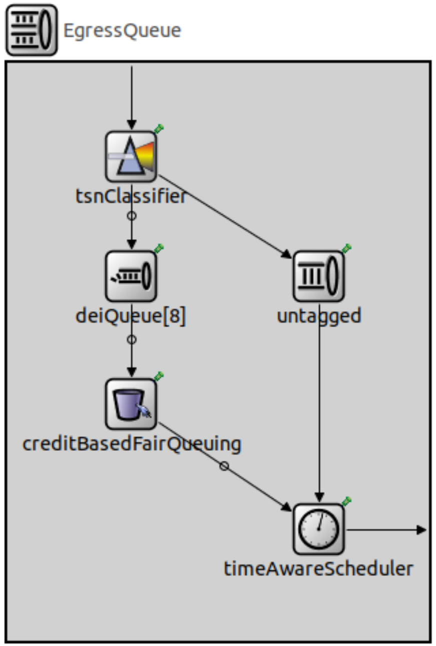


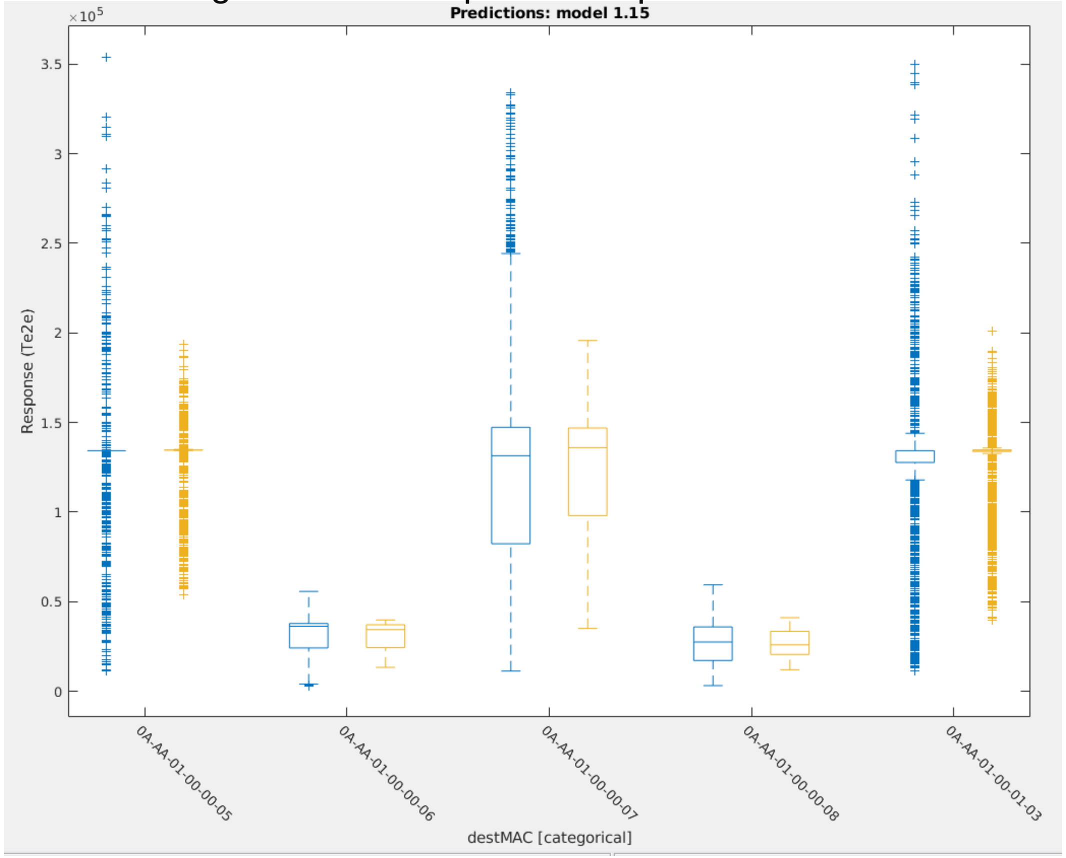
Figure: Egress Queue Implementation

In order to explore as much of the configuration space as possible, random (Monte Carlo) sampling of various non key configuration space parameters has been employed.

PRELIMINARY ANALYSIS

IMPACT OF DESTINATION ON T_{e2e}

Fig A. Model Response Graph for Destination

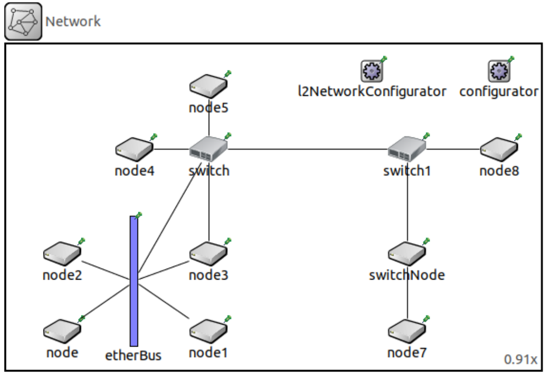


Why this graph?

- Easy to see the variance that occurs even on a path with a single switch.

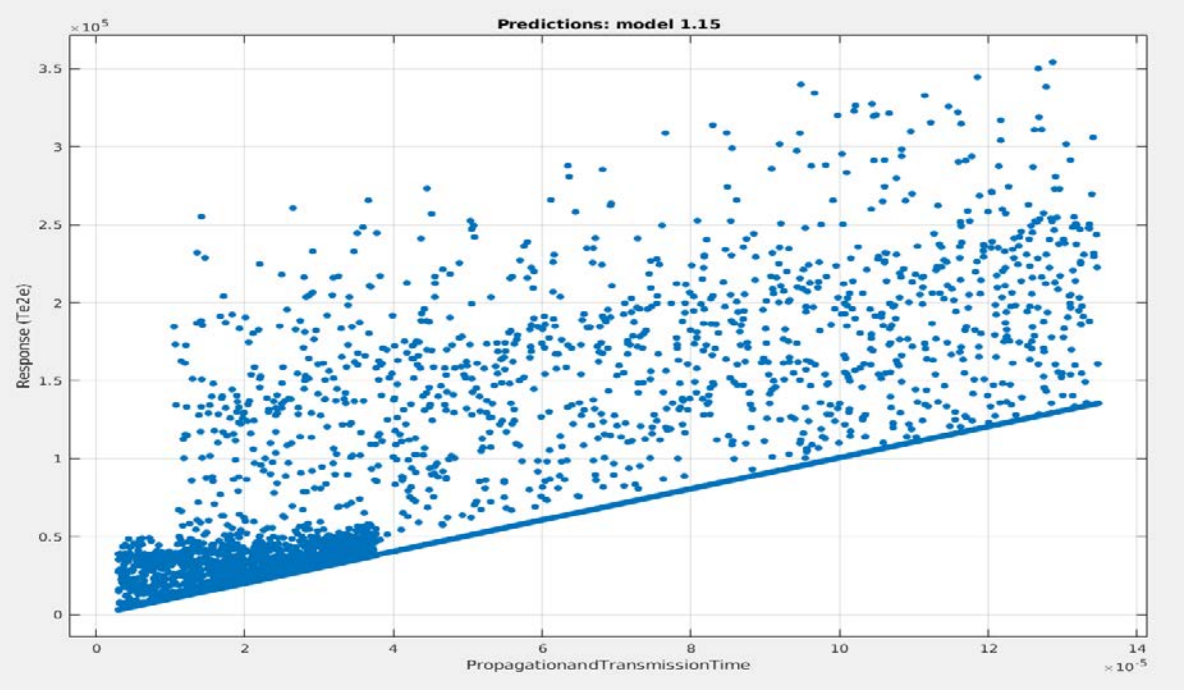
Key Points

- This Ensemble Model has a RMSE of 34.89µs.



PRELIMARY ANALYSIS
IMPACT OF PAYLOAD SIZE ON T_{e2e}

Fig B. Model Response Graph for Propagation and Transmission Time



Why this plot?

- Travel time prediction accuracy depends upon on travel time between to/from switches due to the application behaviour

Points of Interest

- Uniform sampling of Propagation and Transmission is difficult due to the chosen network architecture.
- The variance in response (t_{e2e}) should increase due to the lack application behaviour parameters

FURTHER INVESTIGATION
WHAT NEXT?

Model Improvement

Our models currently only employ:

- Ethernet Frame parameters
- Basic topological structure (e.g. Number of switches on Shortest Path)

We aim to introduce other parameters such as:

- Maximum queue sizes
- Queue utilization
- Analytical upper bound calculations
- And others

With the goal of:

- Developing a method to calculate where on a network, applications with specific Quality of Service requirements, can operate.
- Implementing and comparing above method with real-time parameter assignment.

THANK YOU

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