

QUALITY OF SERVICES SOLUTION FOR EFFICIENT COMMUNICATION WITHIN A DISTRIBUTED URBAN TRAFFIC CONTROL SYSTEM

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Modern Urban Traffic Control (UTC) systems are based on cooperative entities, able to produce optimal signalling strategies independently of traffic control centres. The more information the junction's entities receive from their neighbours, the more effective the distributed system is. But not all the information is critical. For improving the transmission of data and building an efficient QoS structure, a simplified UTC packet is proposed. This solution can be deployed in any real UTC distributed system for guaranteeing that critical traffic parameters are successfully exchanged between its local decision making units in order to ensure a fully adaptive operation.

Keywords: urban traffic control, distributed system, adaptive operation, traffic parameter, communication, quality of services

1. Introduction

Urban traffic control (UTC), as the use of traffic signals to control the flow of traffic on urban surface streets and arterials [1] have gone through various implementations in time. They have evolved from fixed-time traffic signal plans to fully adaptive strategies, able to respond to traffic behaviour in real time [2], [3].

In time, there have been various developments of UTC systems, starting with fixed times control strategies, unable to react to spontaneous changes in traffic progress or incidents, to fully adaptive approaches (centralized or distributed), based on communication with traffic detectors in the field and real time computation of signalling times [2], [3].

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For an UTC system to operate in a fully adaptive mode and provide efficient signalling plans, it is crucial to receive real time traffic data, measured and processed by the detection technologies in the field. Just like in an urban traffic context, the communication network of the system can sometimes be overloaded or even victim of a Denial of Services (DoS) attack that would prevent legitimate information to be exchanged between junctions (for a distributed approach) or between a junction and the traffic control centre (for a centralized approach). In this way, the fully adaptive operation of a distributed UTC system would be obstructed [4], [5], [6], [7],[8].

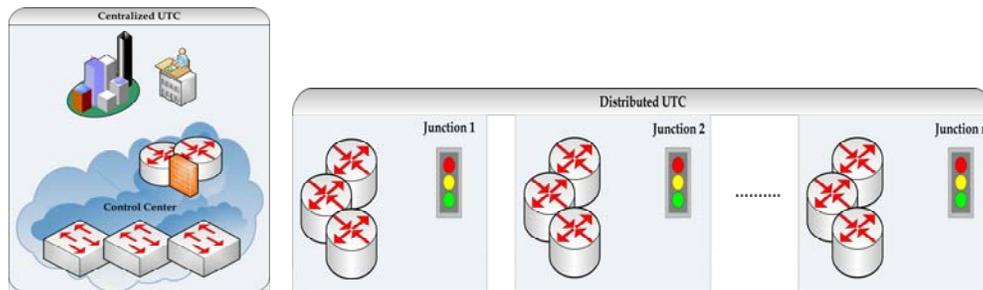


Fig. 1. Centralized and distributed UTC systems concept

By implementing a Quality of Services solution, these issues can be limited because it would ensure that critical information for the system to operate in a fully adaptive mode will always reach the intended destination. Moreover, it allows better flexibility and control over the transmission bandwidth.

However, working autonomously or in an adaptive way could also present problems. There could be errors in the process of traffic monitoring (raw data, communications...), Thus, in such systems data quality is required. The data quality of ITS systems and services has been analysed in several groups and projects. In 2008, the ITS IEEE has defined a standard regarding the data quality [9]. In Quantis project [10], a methodology for quality assessment and assurance for traffic data and information services has been developed. In Easyway project [11], a document focused on the Data Quality Aspects in ITS Framework has been developed. This document presents a general vision of the data quality concepts, examples and it includes a set of best practices. Nevertheless, these studies do not analyse the communication data quality. They are only focused on the ITS services itself [12].

Authors have conducted various research for highlighting the importance of effectively managing the network resources shared between different classes of information by designing QoS solutions, especially for wireless media [13] and distributed systems [14], [15], [16].

The data packet may need to be customized for different QoS solutions, therefore, just like proposed in the present paper, other authors have defined specific node architectures and packet structures suitable to their approach [17].

This paper presents a proposal to solve some congestion problems in the data and information exchange. The solution is based on the classification of the traffic parameters in order to guarantee that the most important parameters reach the destination before the rest.

The present paper is structured as follows: next section presents a proposed structure for the data packet exchanged at the distributed level in the UTC system. Then, in section 3, a QoS solution is described, aiming to ensure that critical traffic information is exchanged between the UTC distributed system's entities in order to maintain fully adaptive operation and cooperation even in difficult conditions of congested communication channels. The solution has been tested in a network simulation environment. Finally, in section 4 the positive results are presented.

2. UTC efficient packet structure

In order to implement an efficient quality of services solution for a distributed UTC system, a simplified structure of data packets has to be defined. The main idea is to separate the data packets according to the carried information, so that they can easier be classified and prioritized using their level of importance.

An Ethernet frame has a maximum length of 1500 Bytes. Besides the data portion, there is a certain overhead added at each layer of the TCP/IP model, therefore an approximation of 1570 Bytes for the maximum UTC packet can be assumed. The real packet length for different UTC systems can vary and it is highly probable that it will never reach the considered 1570 Bytes. However, for the QoS efficiency demonstration, this maximum message value will be used in order to cover any future developments. Forecasting is an important side of an efficient QoS solution, studied and highlighted by various authors as well [18].

Following the TCP/IP model, the proposed UTC packet comprises a header and a data portion. Depending on the equipment and systems manufacturers and developers, part of the fields of the proposed UTC packet can be present or not.

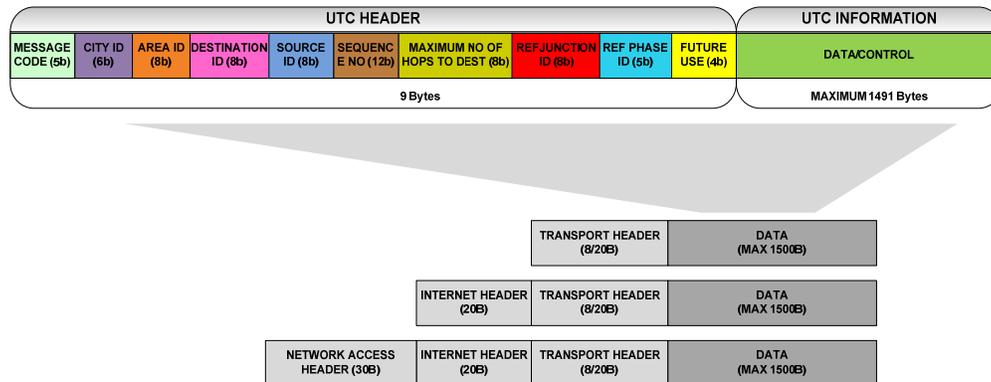


Fig. 2. Proposed structure for an UTC packet

The UTC header is made of 9 Bytes and contains the required information for identifying the message type and the 2 ends of the transmission (figure 2). Its fields are:

- Message code – uses 5 bits to specify the transmitted information type:
 - Control information - communication link and equipment state, synchronization data, etc.
 - Useful data for urban traffic control;
 - Error messages such as unknown source/destination, incomplete or corrupt information, retransmission requests, acknowledgements, etc.
- City and area IDs – the area ID is useful to avoid unnecessary processing of UTC packets by equipments that are not part of the same area;
- Source and destination IDs (traffic controller or specialized decision making unit in the field) – it is an 8 bits coded information, enough to represent a maximum number of 232 signalized junctions within a city;
- Sequence number – a sequence stands for the minimum time unit used for transmitting the data in the system; that is 1 second.
- The maximum number of hops to the destination - depending on the network topology and the permissions on the direct links of any 2 UTC junctions, this number can be precisely known or assumed within certain limits in order to allow a greater network flexibility.
- Reference junction and phase IDs – are useful for validating the offset of each junction in a certain area of the distributed system.
- To complete the UTC header, 4 bits are preserved for future needs.

3. Quality of Services within a distributed UTC system

Once the UTC packet has been defined, it can be used to build the QoS simulation scenario for demonstrating how such a solution can ensure fully adaptive operation of a distributed UTC system, even in difficult conditions of highly saturated communication links.

The efficiency and accuracy of generating signalling plans is increased if the UTC decision making units receive all the traffic information they can get.

The main idea is to guarantee that the most important data (vital for the operation of the system in an adaptive way) would reach the intended destination no matter what.

A successful solution of ensuring the quality of services for an end-to-end transmission depends on how well the delay and packet loss parameters are handled [19]. Therefore, a set of techniques for managing the communication network's resources is mandatory.

Message types within a distributed UTC system

In previous research, an analysis was conducted using a traffic simulation model that permitted the testing of different scenarios using real data collected in the field.

The traffic network used for the demonstration consisted of 5 successive intersections in the southern area of Bucharest, Romania, included today into a modern urban traffic management system with adaptive control operation (BTMS – Bucharest Traffic Management System).

The data used for the simulation scenarios was the traffic flow information manually gathered (observed) in the field in March 2012, during morning rush hour 8 am – 9 am (a mean hourly total of 16,365 vehicles present on the selected road segment).

Different values of the traffic parameters have been applied and the variability of the control parameters has been studied. Measures of effectiveness such as delays, stops, fuel consumption and performance index (linear combination of the first three, and, optionally, excessive queuing) (Minnesota Department of Transportation, 2009) have also been analysed.

The results of the analysis show that the UTC decision making components are able to produce improved signalling plans if they have available as many traffic information they can get from the field detectors.

The chart in figure 3 confirms this last statement. The optimal values were achieved when all the traffic parameters allowed by the simulation tool were known and employed at every step by the system's decision units (the dotted trend line at the bottom of the chart). The best value of the network's performance

index is the smallest one, translated into reduced values for the traffic delays and stops [20].

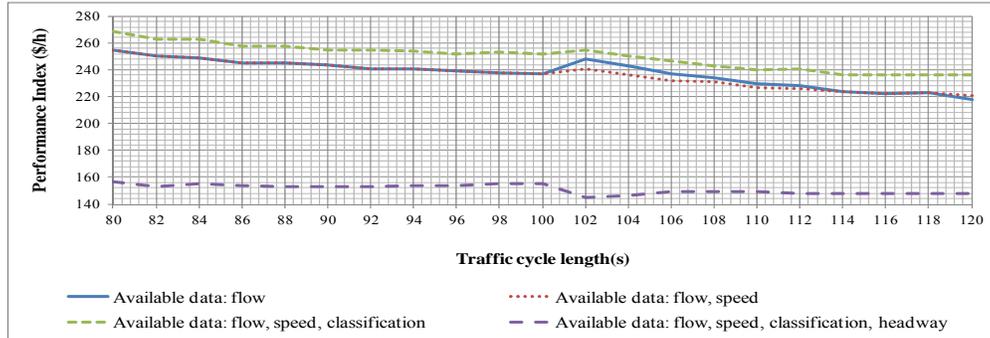


Fig. 3. Performance values for the simulated UTC system depending on the traffic parameters' availability

The simulations results and conclusions allowed the defining of a classification scheme for the traffic variables. This ranking is used in this paper as a determining step for a quality of services ensuring solution within an UTC distributed system.

Assigning priorities to UTC packets

In order to maintain a high level of quality for the transmissions, priorities must be set between different types of messages. It is important to establish the critical data that must be sent to the destination, even with the price of sacrificing other information [21].

For advanced classification needs within a QoS solution, a traffic separation model has been developed in the networking field. DiffServ (Differentiated Services) uses an 8b traffic marking element called DSCP (Differentiated Services Code Point) that makes a correspondence to a prioritization scheme used in legacy systems. DiffServ immediately classifies the information generated within a network and assigns a DSCP identifier to each packet. It does not affect the active applications and ensures interoperability with older equipment [22].

Table 1 shows the classification of UTC information together with a TCP port identifier assigned to each category for the hardware configuration.

Table 1

Classification of UTC data and corresponding TCP port

| UTC data packet type | Priority | TCP port ID |
|------------------------|----------|-------------|
| Signalling plans | 5 | 50000 |
| Traffic flow | 4 | 50001 |
| Headway | 3 | 50002 |
| Vehicle classification | 3 | 50003 |
| Speed | 2 | 50004 |
| Turning percentage | 2 | 50005 |
| Occupancy | 1 | 50006 |
| System diagnoses | 1 | 50007 |

Defining the QoS policy for a distributed UTC system

The last step in preparing the quality of services implementation is to create a policy comprising the classes of information delimited before and establishing the required transmission parameters.

For area coordination, all that needs to be done is to communicate the processed signalling plans between directly connected neighbours and together will be able to apply an optimized strategy. However, as stated before, in order to ensure a higher efficiency and better performance measures, it is highly recommended to communicate all the other local traffic and control parameters as well.

By knowing the size of the data packets about to be transmitted over a communication channel, plus the overhead due to routing protocols and other network administrative information, allows the estimation of the required bandwidth for achieving an efficient data transfer.

For a better demonstration of the QoS functionality, some boundaries have been set for the amount of bandwidth each type of UTC packet is allowed to use (high for signalling plans and limited for the rest of the traffic parameters), plus specific actions in case these values are to be exceeded:

- All the UTC packets, except diagnoses, should be transmitted according to new priorities;
- Some of the non-UTC packets should be transmitted with lower priority and reserved bandwidth;
- The rest of the non-UTC packets plus UTC diagnoses packets should be directly dropped;
- For all the UTC packets except the signalling plans (that should always be transmitted) and for all non-UTC packets, violating the exceed limit should drive to packet drop.

Table 2 summarizes the actions to be taken if the configured bandwidth is exceeded or violated (the exceed portion is also consumed).

Table 2

| Basic actions for the transmission of the UTC packets over a congested channel | | | | | | | | | | |
|---|------------------------|--------------------------------|-----------------------------|-----------------------------|-------------------------------|-------------------------------|------------------------------|------------------|-------------|-------------|
| Packet type | Signalling plan | Traffic flow | Headway | Classification | Speed | Turning % | Occupancy | Diagnoses | ICMP | HTTP |
| Exceed action | transmit | transmit with highest priority | transmit with high priority | transmit with high priority | transmit with medium priority | transmit with medium priority | transmit with small priority | drop | drop | drop |
| Violate action | transmit | drop | drop | drop | drop | drop | drop | drop | drop | drop |

Simulation methodology

For simulating an excessively congested communication channel and configuring the QoS solution for a distributed UTC system, the following software tools have been employed:

- GNS3 (Graphical Network Simulator 3) – a network testing environment offering a graphical user interface and command line configurable equipments [23];
- Wireshark – a data traffic analyzer for monitoring the network's performance [24];
- Colasoft Packet Builder 1.0 – a method of injecting data packets into a modelling environment that has been used for simulating the UTC information [25];
- Cat Karat Packet Builder 1.51.200 – also a packet generator used for building ICMP and HTTP data packets, representing the illegitimate traffic trying to saturate the UTC network [26].

The test has been run for 2 different situations: normal operation and congested network (denial of services scenario simulation as a limit).

An informatics attack aiming to produce the denial of services (DoS) is an attempt of turning the network unavailable for its legitimate users, for a specific or undefined period.

There are various ways of conducting a DoS attack and usually target the interruption of a client-server connection. The hacker can achieve this by interposing himself between these 2 entities and saturating the server with false requests. Even worse than that, if a system has a poor security mechanism, the attacker can replace the server and send corrupted information towards the clients [27]. This kind of attack can seriously impact a centralized UTC system.

4. Results and discussions

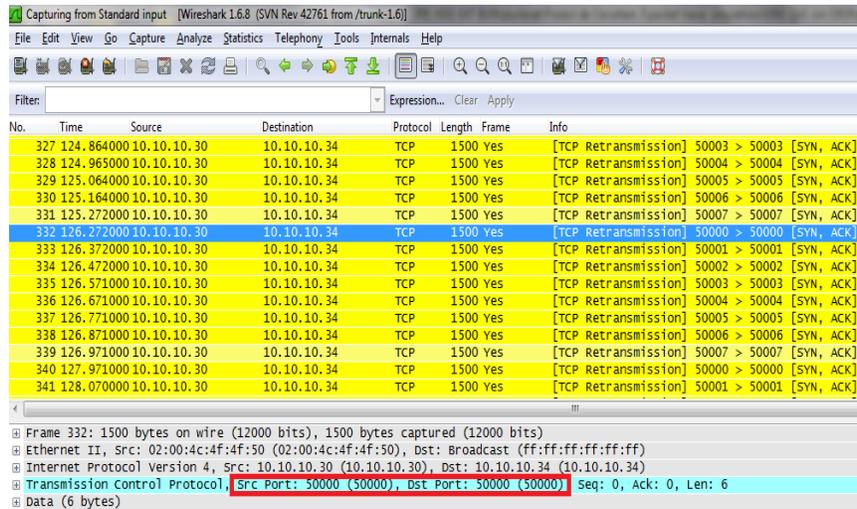


Fig. 4. Wireshark capture for studying the information flow generated in a junction – marking an UTC packet type „signalling plan” identified by port number 50000

Under normal operation, the packets are marked according to the QoS policy applied on equipment R1 (placed in one of the simulated junctions, the source junction), as highlighted in figure 4. The transmission runs smoothly and no data loss occurs.

For the second and most relevant scenario, malicious packets were injected into the network on purpose, to show the improvements offered by the QoS solution in the event of a DoS attack. Therefore, corrupted or oversized packets of data were sent throughout the simulated network. The simulations have been run for 5 minutes in order to evaluate the bandwidth consumption and data traffic behaviour.

Figure 5 shows the statistics regarding the transmitted packets inside the established bandwidth interval, the exceeding data packets and the over exceeding (violating) traffic.

The network attack can be easily identified on the chart, as the number of ICMP and HTTP packets is huge compared to the legitimate information - 18.3 millions malicious packets over 5 minutes, more than enough to saturate the communication channel and block the UTC data transmissions from R1 to R2.

Nevertheless, the measures deployed for limiting the available bandwidth for different types of services turned out to be effective. The green horizontal portion in figure 5 represents the information that will definitely get to its intended destination. Thus, UTC data do reach junction 2 in a higher proportion

than other types of packets, even in difficult conditions of congested communication channel.

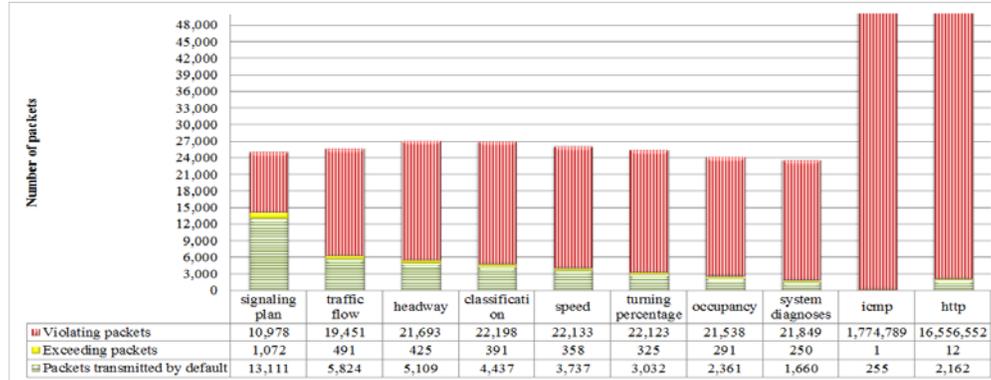


Fig. 5. Guaranteed bandwidth and priority of each type of service

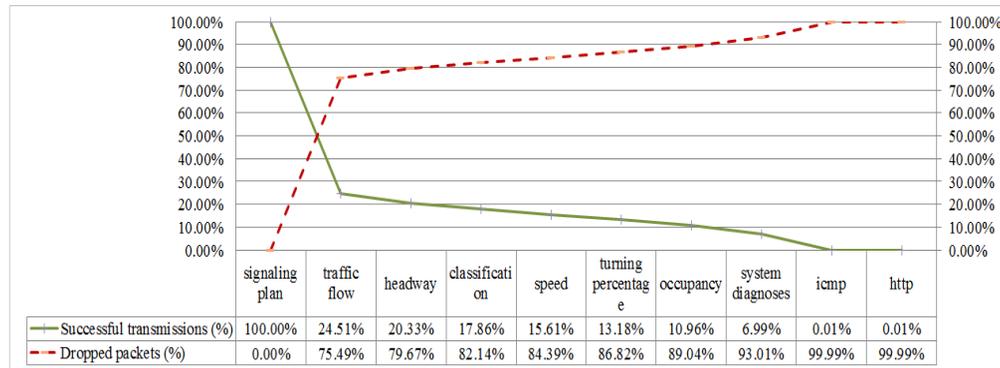


Fig. 6. Successful and unsuccessful transmissions on a highly congested simulated channel

Moreover, figure 6 offers the transmitting percentage of UTC data packets from junction 1 to junction 2. The signalling plans reach their destination with 0% losses according to their highest priority and transmission actions in place. Because the other UTC information is not critical for the system to operate in an adaptive mode, it has been sacrificed in order to ensure the signalling plans are being transmitted. Their drop percentage is high, up to 93% for diagnoses packets.

For what concerns the illegitimate data traffic (ICMP and HTTP), it was 99.99% dropped.

5. Conclusions

The current paper builds upon the idea of developing a distributed UTC system, by customizing a QoS solution for improved outcomes related to seamless adaptive operations through a higher level of fault tolerance and reliability.

Each existing UTC system employs its own information management methods and protocols, with corresponding security measures. The idea presented in the current paper is the development of a simplified structure for the UTC data packet that can be used or adapted to existing or conceptual UTC systems. The model is based on breaking down traffic information into separated packets according to the traffic parameters inside. In this way, traffic information flowing between local junctions can be easier classified and prioritised.

Urban traffic and control parameters needed to be classified according to their contribution to traffic optimization. This ranking scheme served as the underlying concept of the proposed Quality of Services presented in the paper. The aim was to guarantee the critical information availability for each junction, even in excessively loaded communication channel situations. The signalling plans are the most important data for ensuring cooperation between neighbouring nodes and for establishing an optimal control strategy at an area level. Therefore, their availability and integrity has to be ensured.

After testing the QoS implementation scenario in a virtual simulation environment and studying its operation when the communication bandwidth is consumed by undesired information, the main conclusion is that it is a viable solution for achieving a greater control over the transmission link and maintaining the UTC system's fully adaptive operation. Not only does it allow a higher flexibility and control over the available bandwidth, but also ensures that packets containing the signalling plans will successfully reach their intended destination even in difficult, saturated conditions.

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