AD-HOC NETWORKS OF TRAFFIC CABINETS

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Modern traffic management systems are very complex and consist mainly of field equipment and a command centre. Of course, an important element is the communication system, which must be fast and reliable. For smaller cities the cost of implementing such system is prohibitive and, thus, traffic issues can't be properly solved. The system proposed in this article represents a solution, by creating ad-hoc networks of traffic cabinets that are able to communicate with each other without the necessity of a command centre.

Keywords: traffic management systems, traffic congestions, ad-hoc networks

1. Introduction

Traffic management systems (TMS) depend on the communication infrastructure to ensure real-time delivery of messages between control centre and local stations. The links are typically done using fibre optic, having many benefits against cable or wireless, but with the downside of costs. For many smaller cities this is a big issue, and hence, although there are congestion problems that may be solved by implementing a TMS, this can't be installed due to the costs involved.

A solution to this problem may be to eliminate the control centre and the expensive communications and use only local posts that are able to communicate with each other and establish zonal optimization areas. Wireless communication between traffic cabinets may be a support for ad-hoc networks; there are many viable solutions that could support this information exchange.

In this paper this solution will be analysed from the communication channel point of view, trying to define the proper transmission method.

2. Network concept

Traffic cabinets usually function in a master-slave configuration, sending traffic data to a control centre and receiving signalling times that must be

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implemented in traffic lights. However, in some TMS, such as UTOPIA/SPOT, there are two decision layers:

- Local decision, taken by traffic cabinets, according to the information they receive from local detectors and also considering the data obtained from neighbours cabinets. Based on this, traffic cabinets decide upon the best signalling times for the junction they control, according to current traffic conditions;
- Centralized decision, taken in the control centre, having the goal of global optimization; based on this, traffic cabinets may consider small variations compared to the decision taken locally.

Master-slave network configuration suffers sometimes from bandwidth bottlenecking, due to the fact that all control processing happens in one place: the master device. This creates another possible issue: a single point of failure. If the central point malfunctions, the entire system becomes unusable.

An alternative is to create a peer-to-peer configuration, having communication (and also control) distributed among devices in the field. Thus, each traffic cabinet may communicate with others without having to pass the data through a control centre. The main advantage of a peer-to-peer configuration is that if one device goes down, the other devices can continue to function as usual. However, a "master" device may be installed in the network having only the purpose of monitoring. This solution provides some enhancements, such as the capability of sending commands to the whole system from outside through a single point of access and the fast detection of failures in the network. [1]

A wireless ad-hoc network (WANET) is a decentralized type of wireless network. This type of network does not rely on a pre-existing infrastructure, such as routers or access points. Each node participates to the communication by forwarding data to other nodes; the nodes forwarding data are established dynamically, based on the network connectivity. [2]

An ad-hoc network refers to a set of devices that have equal status on a network and are free to associate with any other that are in their communication range. Ad-hoc networks have more advantages:

- Ease of deployment
- Speed of deployment
- Decreased dependence on infrastructure.

Considering all these aspects, the proposed solution for a traffic management system is to create a real-time self-configuring network of traffic cabinets based on two basic principles:

1. Establishing dynamic zones of interest. Two junctions having a large number of vehicles traveling between them are in the same zone. A junction that has a large number of vehicles arriving from all entrances

may setup two or more different zones with its neighbours. A traffic cabinet in such a junction may be set (at the installation of the system) to have this capability of zone setting.

2. The network is ad-hoc, having the advantages of real time reconfiguration in cases of malfunction of one or more traffic cabinets or addition of new units. The information propagation is considered proper even in case of malfunction of more devices, since:
   a. If a traffic cabinet has direct line-of-sight with other, even if the one in between is not functioning, data can be exchanged.
   b. If a traffic cabinet is not functioning and the connection between its neighbours is broken, there is a probability that the distance is too big and, hence, a junction's traffic information wouldn't be relevant for the other.

3. Wireless communication

The information that must be transmitted from one traffic cabinet to another may be included in the following categories:

- Synchronization data;
- Communication management data;
- Traffic volumes data;
- Traffic lights timing data.

The information needed to be transmitted is quantified as:

$$Br = 2 * BW * log_2 L \quad (1)$$

where Br is the maximum bit rate, BW is the bandwidth and L is the number of signal levels used to represent data. Considering Br known, resulted from the data mentioned above and L = 2, we may calculate BW as:

$$BW = \frac{Br}{2} \quad (2)$$

One traffic controller must communicate with its neighbours. Considering a mesh network topology and the necessity to ensure the line of sight for wireless communication between traffic controllers, one unit must communicate with a maximum of 10 other units (in very complex junctions). A message containing data mention above, coded in order to ensure the detection and recovery of communication errors is estimated to have a maximum length of 1000 bits. Considering the necessity of transmitting 10 messages per second it results a bit rate of 10000 bps. Thus, BW must be 5000 Hz = 5 kHz.

The Shannon capacity of the communication channel is given by:

$$C = BW * log_2\left[\frac{S}{N} + 1\right] \quad (3)$$

where C is the channel capacity, BW is the bandwidth and S/N is signal-to-noise ratio.

In table 1 are given the values in dB of SNR ratio used for WiFi.

Table 1

SNR values for WiFi [3]

SNR value [dB]	Signal strength
> 40	Excellent
25 - 40	Very good
15 - 25	Good
10 - 15	Low
5 - 10	Very low

Considering a SNR of 31 (a very good signal strength as defined above):

$$C = 5000 * log_2 32 = 25000bps \quad (4)$$

This is enough [4] to ensure the transmission of data with Br calculated above of 10000bps.

Orthogonal frequency-division multiplexing (OFDM) may represent one solution that could be used for communication. It is a method of encoding digital data on multiple carrier frequencies (N), being a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. It has an advantage of high spectral efficiency as compared to other double sideband modulation schemes [5]. It also provides low sensitivity to time synchronization errors and good protection against co-channel interference and, hence, it is suitable for high data rate, fast communications.

OFDM transmits a large number of narrowband sub-carriers, closely spaced in the frequency domain. Each of the sub-carriers is modulated using a conventional modulation scheme, at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. In order to avoid a large number of modulators/demodulators and filters at the transmitter and at the receiver, some modern digital signal processing techniques may be used, such as fast Fourier transform (FFT). [6]

Each sub-carrier can be described as a complex wave:

$$s_c(t) = A_c(t)e^{j[\omega_c t + \Phi_c(t)]} \quad (6)$$

The real signal is the real part of $s_c(t)$. $A_c(t)$ and $f_c(t)$ represents the amplitude and phase of the carrier. Both can vary on a symbol by symbol basis, but their value is constant the symbol duration period t.

As stated above, OFDM consists of many sub-carriers. Thus, the complex signal $s_s(t)$ is represented by:

$$s_s(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t)e^{j[\omega_n t + \Phi_n(t)]} \quad (7)$$

where

$$\omega_n = \omega_0 + n\Delta\omega \quad (8)$$

This represents a continuous signal. If we consider the waveforms of each component of the signal over one symbol period, then the variables $A_c(t)$ and

$f_c(t)$ have fixed values, which depend on the frequency of that particular carrier, and so we may consider that $\Phi_n(t) = \Phi_n$ and $A_n(t) = A_n$.

If the signal is sampled using a sampling frequency of 1/T, then the resulting signal is represented by:

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j[(\omega_0+n\Delta\omega)kT+\Phi_n]} \quad (9)$$

The time frame considered is limited to N samples. It is convenient to sample over the period of one data symbol. Thus we have t =NT.

From equation 9, considering that ω_0=0, then the signal becomes:

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j\Phi_n} e^{j(n\Delta\omega)kT} \quad (10)$$

Equation 10 can be compared with the general form of the inverse Fourier transform:

$$g(kT) = \frac{1}{N}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right) e^{j2\pi k/N} \quad (11)$$

In equation 10, the function $A_n(t)e^{j\Phi_n}$ represents the definition of the signal in sampled frequency domain, and s(kT) the time domain representation. Equations 10 and 11 are equivalent if:

$$\Delta f = \frac{\Delta\omega}{2\pi} = \frac{1}{NT} = \frac{1}{t} \quad (12)$$

This is the same condition that was required for orthogonality. Thus, one consequence of maintaining orthogonality is that the OFDM signal can be defined by using Fourier transform procedures.

Considering a number of bits per symbol of 4, corresponding, for example, with QAM [7] result a baud rate of 2500 to transmit the 10,000 bps calculated above. This means a useful symbol duration t = 0.4 ms and a total passband bandwidth of $N\Delta f$ = 5 kHz (calculated above). As Δf = 2.5kHz, it results:

$$N = \frac{BW}{\Delta f} = \frac{5000\,Hz}{2500\,Hz} = 2 \quad (13)$$

As a result, considering the simplified model detailed above OFDM may be used for communication in an ad-hoc network of traffic cabinets, requiring only 2 sub-carriers.

4. Security

Although ad-hoc wireless networks present the advantages mentioned above, the most important issue to be treated is the security of the communication. Wireless networks are vulnerable to hackers and represent the most used gate for unauthorized access to any network. [8]

The most effective way to secure the communication is to encrypt data over the network. The encryption algorithm may use a class of private keys that are known only by traffic cabinets. Also hash functions may be used; these have two main properties:

- It's hard to find two inputs with the same output (a collision)
- It's hard to find an input matching a given output (a pre-image).

The use of these methods [9] significantly reduces the risks. In addition, there is usually little interest to hack these types of networks.

5. Conclusions

Ad-hoc networks of traffic cabinets may represent a solution for smaller cities. There is the need to ensure a line-of-sight between emitter and receiver, but repeaters can be used where this can't be obtained. The wireless communication protocol analysed provide the capability of assuring information exchange. Security is a special issue to be further approached, due to the fact that all the information a traffic controller gets directly influence signalling times and so, wrong data may disturb traffic conditions.

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