# TRANSMISSION OF POLLUTION DATA TO TRAFFIC MANAGEMENT SYSTEMS USING MOBILE SENSORS

Maria Claudia SURUGIU[1], Răzvan Andrei GHEORGHIU[2], Ionel PETRESCU[3]

*Modern traffic management systems use, in addition to data on the number and categories of vehicles, information on pollution in order to include them in the algorithm used and to determine avoidance of areas with out of scale parameters. These data can be collected at road junctions, using fixed detectors, or between them, using sensors placed on vehicles, such as public transport vehicles. Stored information can then be transferred to the traffic management system at intersections through traffic controllers. This paper presents a solution for this communication, performing calculations necessary for the communication channel.*

**Keywords:** urban pollution, traffic management systems, pollution detectors, wireless sensor network, data transmissions

## 1. Introduction

Pollution is a real problem in cities, especially the one caused by road traffic. To deal with this, traffic management systems started to include in their algorithms for traffic guidance information about polluted areas. The goal is to achieve a redistribution of emissions so areas with exceeded pollution would not exist anymore. In order to do this pollution sensors must be used. These may be fixed or mobile, gathering data in road junctions or between them. Mobile sensors may be installed on public transport vehicles and can send the data to traffic management system in intersections, by communicating with traffic controllers.

Communication parameters have been evaluated in order to determine the most suitable communication channel capable of ensuring a fast and reliable connection in intersections for data exchange.

[1] Senior Lecturer, Dept. of Telecommunications and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: claudia.surugiu@upb.ro
[2] Junior Lecturer, Dept. of Telecommunications and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: andrei.gheorghiu@upb.ro
[3] Junior Lecturer, Dept. of Telecommunications and Electronics in Transports, University POLITEHNICA of Bucharest, Romania, e-mail: npcrank@yahoo.com

## 2. Proposed solution

In order for a traffic management system (TMS[4]) to use pollution information, detectors must be installed in the field, in specific spots that may offer the best possibility for data collection (Fig. .1).

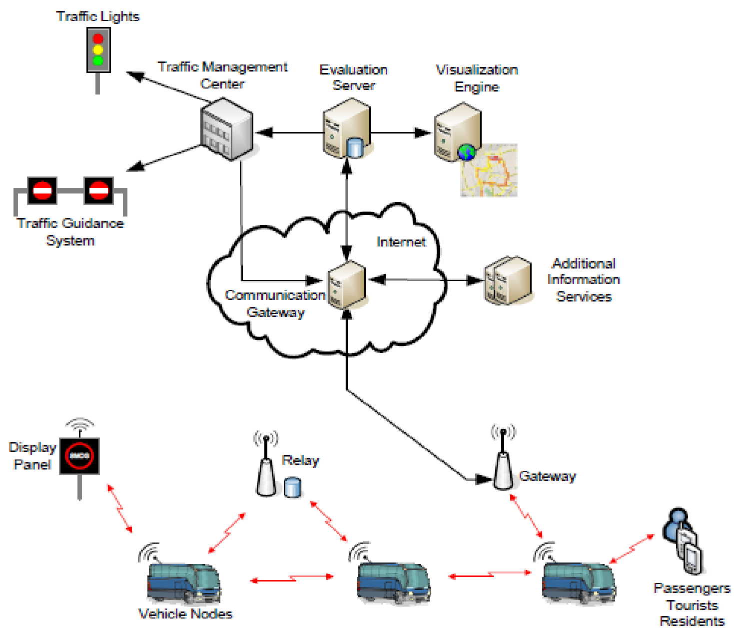


Fig. 1. Basic architecture [8]

There may be:

- Fixed detectors, that offer data from congested junctions, where there is a significant probability for pollution indicators to grow out of scale, at least at peak hours and
- Mobile devices, installed on vehicles with the goal of gathering data between junctions, that will allow the TMS to have a complete picture of the pollution spreading along the whole road network. These, however, can't be installed on private vehicles, so the best option would be to use public transport vehicles. This may be a proper solution, due to the fact that cities with congestion issues usually have public transport.

[4] TMS – Traffic Management System

## 3. Data transmission

Considering the second type of devices defined above, communication concerns arise, as the information gathered along a path (between two main junctions) must be delivered to TMS in a short time, considering that the public transport vehicle the detector is installed on may pass through the junction at full speed if the traffic light is green. As in the cities communications have barriers represented by buildings, there are many signals transmitted along the roads, which meet each other at junctions.

So, the problem is to ensure a proper transmission, with a suitable modulation scheme, that will allow the data to be sent with minimum errors in a short period of time.

In the following we will analyse different modulation techniques, trying to evaluate, by experimental models, the error rate for each of them.

### 3.1 MSK and GMSK/GFSK. Modulation Basics

In today's modern digital high speed communication systems primary consideration is to achieve modulation with power spectrum of acceptable bandwidth and constant amplitude of the modulated signal. Some of the most efficient modulation techniques are MSK[5] and GMSK/GFSK[6] [1-3]. Both modulations, MSK and GMSK/GFSK, are derived from the ordinary Frequency Shift Keying (FSK[7]) modulation scheme, which is a digital version of frequency modulation (FM[8]). An FM signal is defined as:

$$u_{FM}(t)=U_m\cos[\omega_c t+\varphi(t)] \qquad (1)$$

Where *Um* is the amplitude, ω*c* is the carrier frequency, and φ (*t*) is the phase of FM signal, which is for FSK equal to:

$$\varphi_{FSK}(t) = 2\pi\frac{m}{T_b}\int_0^1\sum_{i=0}^{\infty} b_i g_{RECT}(\tau - iT_b)d\tau \qquad (2)$$

Where *m* is the modulation index, *Tb* a symbol interval and $g_{RECT}(t)$ the pulse shape function. In ordinary FSK the digital signal that modulates an FM modulator is a rectangular bipolar Non Return to Zero[9] (NRZ) bit sequence with symbol values $b_i \in \{-1, 1\}$.

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5 MSK - Minimum-Shift Keying
6 GMSK/GFSK - Gaussian Minimum Shift Keying/
7 FSK - Frequency Shift Keying
8 FM - Frequency Modulation
9 NRZ - Non Return to Zero

$$g_{RECT} = \begin{cases} U_m, & -\frac{T_b}{2} \le t \le \frac{T_b}{2} \\ 0, & \text{othervise} \end{cases} \tag{3}$$

MSK is a continuous phase modulation scheme. The modulated carrier does not contain phase discontinuities and frequency changes at carrier zero crossings. It is typical for MSK that the difference between the frequency of logical 0's ($f_0$) and 1's ($f_1$) is equal to half the data rate.

MSK modulation makes the phase change linear and limited to ±(π/2) over the symbol interval. Due to the linear phase change effect, better spectral efficiency is achieved. That means that MSK is ordinary FSK with the modulation index set to 0.5, and it is defined as:

$$m_{MSK} = \Delta f T \tag{4}$$

Where peak frequency deviation $\Delta f$ is given by:

$$\Delta f_{MSK} = | f_1 - f_0 | \tag{5}$$

The present study was performed as a demonstration for transmitting and receiving binary data. Due to the fact that the FSK and PSK modulation is less sensitive to noise, we will consider that the system uses one of the two modulations. In case of the FSK modulation the band width is:

$$B = (1 + d)S + 2\Delta f \tag{6}$$

Where: $B$ = bandwidth, $d$ = factor which value depends on the modulation and filtration with a value between 0 and 1, $S$ = symbol rate and coincides in this case with the bit, $\Delta f$ = frequency deviation.

$$S = N\frac{1}{r} \tag{7}$$

Where: $S$ = the number of symbols per second, $N$ = the bit rate, $r$ = the bit number per symbol.

For the FSK modulation with $r = 1$, we consider $d = 1$, $B = 100$ kHz, $r = 1$ and $2\Delta f = 50$ kHz. Then from the equations (6) and (7) it results that $N = S =$ 25kbps, enough speed for a single transmitter to serve an intersection. The channel capacity is affected by electromagnetic noise, according to formula (8) and has the same value everywhere. Therefore, in noisy areas distance between nodes should be reduced.

$$C = B\log_2(1 + SNR) \tag{8}$$

Where: $C$ = the channel capacity in bps, $B$ = the bandwidth in Hz, $SNR$ = signal to noise ratio in dB.

In practice is working with SNR[10] measured in dB and the transformation formula is:

$$SNR_{dB} = 10\log_{10} SNR \quad (9)$$

To calculate the channel capacity in practice is used the formula (10):

$$C = B\frac{SNR_{dB}}{3} \quad (10)$$

In table (1) are given the values in dB of SNR ratio used in Wi-Fi.

*Table 1*

**SNR values for WiFi communication**

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

GMSK is also the two-state modulation technique derived from MSK [4], [5]. The phase continuity between each state is assured, when the carrier frequency is equal to the integer multiple of the signal bit rate. In addition, the input square modulation signal is filtrated with the Gaussian filter.

$$g_{RECT} = \begin{cases} U_m \cos\frac{\pi t}{T_b}, & -\frac{T_b}{2} \le t \le \frac{T_b}{2} \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

GMSK/GFSK modulation can be realized by both parallel [6] and serial synthesis [7]. It differs from the ordinary MSK by using the Gaussian LP filter or Gaussian shaper on the input of the I-Q or FM modulator.

Impulse response of the Gaussian pulse shaping filter is given by:

$$h_{GAUSS}(t) = K\sqrt{\frac{2\pi}{\ln(2)}}Be^{-2\frac{(B\pi)^2}{\ln(2)}t^2} \quad (12)$$

Gaussian shaped bit stream $g_{GMSK}(t)$, which is equal to convolution of $g_{RECT}(t)$ and $h_{GAUSS}(t)$ becomes:

$$g_{MSK}(t) = -\frac{K}{2\sqrt{\ln(2)}}\left[E_{rf}\left(2B\pi\frac{t-\frac{T_b}{2}}{\sqrt{\ln(4)}}\right) - E_{rf}\left(2B\pi\frac{t+\frac{T_b}{2}}{\sqrt{\ln(4)}}\right)\right] \quad (13)$$

Where $E_{rf}(t)$ is error function given by:

$$E_{rf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt \quad (14)$$

[10] SNR - Signal-to-noise ratio

### 4. Experimental models

In order to estimate the error rate for different modulation schemes a Matlab program was developed, considering a signal containing a sequence of 300 bits propagating through an Additive white Gaussian noise channel (AWGN[11]). For each modulation technique the simulation was run 100 times in order to determine a mean error rate. The model used a SNR in the interval [0…15] in order to determine the SNR at which the error rate drops near zero.

The following graphics (Figs. 2-4) show the results for PSK, FSK, MSK and GMSK modulations.

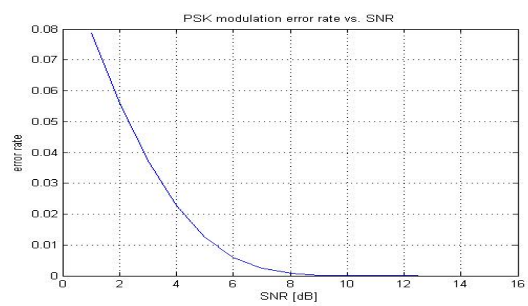


Fig. 2. Error rate for PSK modulation

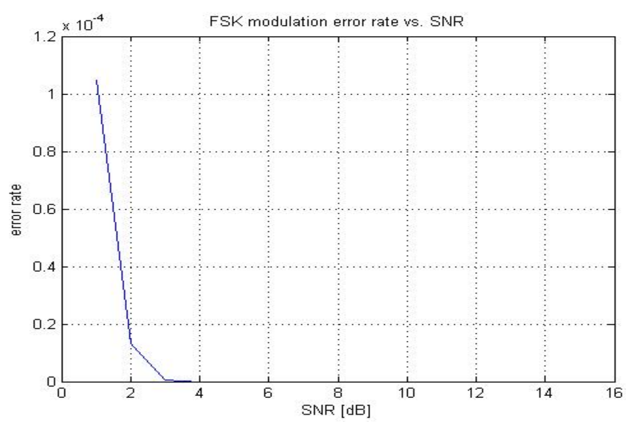


Fig. 3. Error rate for FSK modulation

[11] AWGN - Additive white Gaussian noise

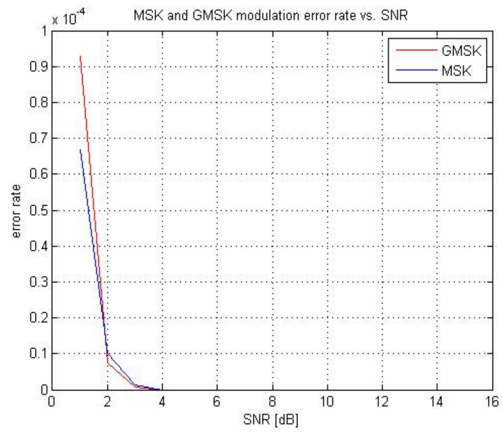


Fig. 4. Error rate for MSK and GMSK modulations

## 5. Results

For FSK, MSK and GMSK modulations (Fig. 3, 4), the error rate drops down to 0 for a SNR ≈ 3. For PSK modulation (Fig. 2), the error rate nears zero for SNR ≈ 10. This means that a better antenna is needed (with a higher signal strength), considering all the radio interferences that occur in urban road junctions. Considering the values obtained by simulation we may conclude that the best modulation scheme for noisy environments is MSK.

## 6. Conclusions

A WSN[12] Based Air Pollution Monitoring System was designed and tested using a wireless sensor network. The system may be used to collect pollutant gases such as $CO_2$, $NO_2$, and $SO_2$ from environment. The pollution data from various mobile sensor arrays is transmitted to a central centre that makes the information available to government authorities. The data reveals the pollutant levels and their conformance to local air quality standards, but the system may also use the AQI (*Air-Quality-Index)* to evaluate the level of health concern for a specific area.

Regarding data communication, from the tests performed, we concluded that it is possible to transmit the correct messages, from mobile sensors to receivers in the junctions, even when a vehicle is passing through the area at high speed. MSK and GMSK modulation techniques provide (theoretical) zero error

[12] WSN - Wireless Sensor Networks

rate for SNR above 4dB. Future tests must, however, be performed, in real conditions, to validate this solution.

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