How to Optimize the Spectrum: the Oil Experience

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Abstract

Since several years, sustainable development (SD) has become an important issue in many technical domains. One of the main contributors in CO_2 emission is undoubtly petrol engine. This explains why car industry was the first interested in finding solutions to decrease oil consumption and to optimize car usage. Starting from the idea that spectrum is a natural and public resource which should be carefully used and shared, in this paper we apply to spectrum usage at every levels (standards, equipments, usage, etc.) analogies coming from oil experience.

1. Introduction

Not so many years ago, SD was only the preoccupation of ecological groups. However, SD has become an issue and an aspiration of our civilization since Resolution 42/187 of the United Nations General Assembly in December 1987. The Brundtland Commission defined SD as the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". Then several United Nations Conferences (from Rio de Janeiro-1992, to Copenhague-2009) have confirmed this important issue. One of the most obvious aspects of SD is the climate change and the CO_2 emission.

It is clear that automobile is one of the most important contributors in CO_2 emission. This is why automobile industries in general as well as many governments on the planet have tried as first step to decrease automobile CO_2 emission, in order to decrease global warming. Therefore other industry which would also decrease its own emission may, in a useful way, benefit from the automobile industry experience. Currently, 3 % of the world-wide energy is consumed by the ICT infrastructure which causes about 2 % of the world-wide CO_2 emissions (which is comparable to the world-wide CO_2 emissions by airplanes or one quarter of the world-wide CO_2 emissions by cars). In parallel another challenge of future wireless radio systems is to globally reduce the electromagnetic radiation levels in order to have a better coexistence of wireless system (less interference) as well as a reduced human exposure to radiations. This last point was the main objective of [2]. The first paper related to Green radio, thanks to Cognitive Radio concept, as a way of decreasing electromagnetic pollution (mainly from the human exposure point of view) has been presented several years ago in a URSI General Assembly [2]. But, at that time, this type of preoccupation was not in the trend.

The values of carbon footprint of ICT are very impressive. They have been confirmed by a lot of studies and reported in many conferences and workshops as the recent "Next Generation Wireless Green Networks Workshop", held in SUPELEC in November 2009. In [3], we claimed that Cognitive Radio, thanks to its sensors, is an enabling technology for Green Communications. It is exactly what we named Green Cognitive Radio (GCR).

In this paper we extend the analogy we did in [4] between Cognitive Radio and vehicle. This analogy was made from the sensors and from the “Sensorial Radio Bubble” point of view, in order to derive spectrum usage rules accordingly with traffic regulations. In this paper the analogy is made in order to derive spectrum optimization and power consumption mitigation methods accordingly to those already proposed for oil decrease for cars. Table 1presents the analogy we propose between automobile and radio communications domains.

In this paper, we consider spectrum as a natural and public resource which should be carefully used, and shared. It is a finite resource because frequency exists if and only if there is sufficient energy to generate the waves. From the usage point of view, spectrum should be theoretically infinite, as it is constantly renewed.

Automobile Domain	Radio Communications Domain
Oil	Spectrum
consumption=number of kilometers per liter	Spectrum Efficiency=number of bits/Hz/s/m²
Speed	Bit rate
Travel distance	Source Throughput
Motor	Radio Access Technology (RAT)
Car	Equipment (terminal, box (wifi)…)

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Smart car	Cognitive phone
Intelligent Transportation System	Cognitive Radio
Driver	user

Table 1: Analogy between automobile and radio-communications domains

2. Analogy with the motor and vehicle optimization

2.1 Motor optimization

Motor optimization means that motor designers did a lot of progress in order to consume less gasoline, in other terms to do more kilometers with one liter of gasoline. Here the analogy means to transmit more throughput with the same spectrum (bandwidth). Therefore, any signal processing study investigating ways to increase the wireless networks capacity, under the constraint of constant bandwidth, are contributing to this analogy. Let us just take a few examples of these topics: MIMO processing, near-Shannon limit channel-coding schemes, cooperative communications and relying, etc. Here is an example from [3], which was proposed to decrease the transmitted power for Green radio Communications. Another way to interpret this example consists in saying; when the conditions are good, it is possible to activate some signal processing technique in order to increase the throughput.

This example proposes to use the SNR sensor (in CR context) to activate a channel code (after agreement between Tx and Rx), in order to increase the throughput for the same BER. This could be illustrated by the following example: After the receiver has checked the quality of the transmission i.e. has checked if there is sufficiently good Signal to Noise Ratio (SNR), good channel estimation and sufficient Bit Error Rate (BER) for the desired Quality of Service (QoS), it can then decide to use or change a channel code in order to increase the throughput while keeping the BER sufficient for the QoS, as it is illustrated in Figure 1 (see the horizontal arrow). Similarly, it could also decide to change other parameters of the physical layer with this objective in mind.

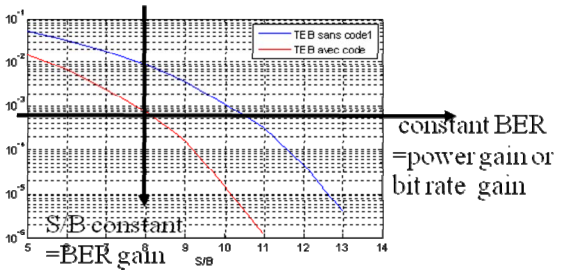


Figure 1: Gain in performance versus bit rate increase.

2.2 Vehicle optimization

Vehicle optimization means that the vehicle should be adapted to the service it should provide. For example for short trip in downtown, a small car (motor) could be sufficient. In our analogy this could mean to use the adequate standard to transmit the data, (thanks again of CR).

3. Analogy with car usage

3.1 Speed mitigation and engine off at traffic lights

Driving slow at a constant speed saves oil and therefore increases the number of kilometers for one liter. The same way, decreasing the bit rate, for example by decreasing the symbol frequency, will decrease the bandwidth spectrum. Another point is to stop the motor at when the traffic light goes red, so that it saves gasoline. The analogy here refers to put off the equipment instead of standby mode in the radio domain.

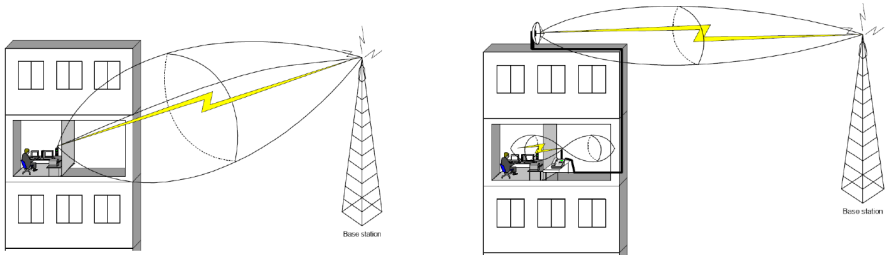
3.2 Travel optimization

3.2. 1 Overall distance minimization

To minimize the overall distance of the travel is equivalent to minimize the overall throughput of the sources to be transmitted. Any coding technique that decreases, for example the global throuput of video services, meets exactly this analogy.

3.2.2 Use of other means of transport

To use other means of transport (like trains, which cause less CO_2 emission) is another way to decrease the overall distance done by cars. In our analogy, that means that instead of using radio spectrum for transmitting data, we may use wired connection, optical connections or other means which need to be discovered. Figure 2 is a good illustration of how to choose the best standard according to spectrum optimization. Inside the building the user uses a wired connection and there is a wireless connection from the roof directly to the BS. Here there are some indirect gains such as to decrease the transmission power, to decrease the electromagnetic pollution. In [7], the proposed solution to decrease consumption consists, in femtocells systems, to design the backhaul with wired instead of wireless connections. This is also an illustration of our analogy.



(a) **(b)**

Figure 2: Wireless Internet access: (a) direct from terminal; (b) wired inside the building and then through a centralized wireless directional access point outside the building

3.3 car-pooling and public transit analogies: spectrum sharing

3.3.1 Car-pooling analogy

Car-pooling means that user (drivers) transport in their own car others passengers, and generally they share the price of the travel. So, everyone is a winner, because one car for four passengers emits less CO_2 than four cars with one passenger each. The travel price is divided by four for each passenger. We may imagine exactly the same type of process considering that the car is the box of the user. Generally the box is used only few hours per day and not at the maximal throughput. Instead of having four users each with a box they may share one box and also the inherent price.

3.3.2 Public transit analogy

We pursue now our analogy with public transit which is a very good alternative to decrease the number of cars, especially in downtowns. This offers other indirect gains as fewer accidents, less noise, more parking space, etc.

- Multiplexing several services in a bit stream for a given channel spectrum is a good example of this analogy. For example, it was exactly the scenario for the transition between analog broadcasting signals to digital broadcasting signals. In fact, in one 8 MHz channel bandwidth, instead of having one TV program (SECAM for example) we obtain 6 TV programs with MPEG2 coding scheme. These programs share the same bandwidth therefore an operator (the broadcaster) is needed to manage this multiplexing.
- Generalization of hot spots could be the equivalent for the spectrum usage. Hot spot for a building, for a street, etc. This also offers others indirect gains as less electromagnetic pollution, less consumption. Figure 2 is again a good illustration of such possibility.

3.3.3 Car sharing analogy

Cars are very often underused. It is why new services are appearing that proposes to share cars. That means (exactly as for bicycle sharing) the user can use the car for few hours for a small price. The advantages of this type of solution are obvious. The analogy we do here is to share the existing spectrum which is underused, whatever the way to share it, is.

It could be thanks to a new service provider which offers spectrum pooling, it could be direct sharing between primary user and secondary users, or it could be opportunistic sharing as it is presented below, thanks to the CR tool.

CR was proposed firstly for spectrum optimization. Therefore the use of CR for this aspect of Green Communications is obvious. In the green context, it is exactly what H. Zhang named "Green Spectrum" in[5]. This aspect is described in Figure 3, in which the spectrum opportunities are identified for three consecutive standards.

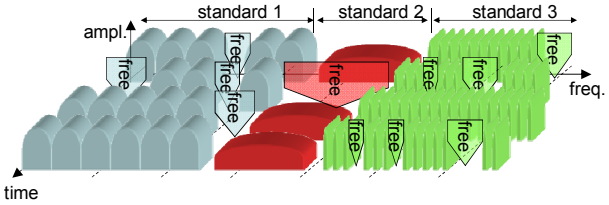


Figure 3: Communications opportunities in the frequency/time plan for three consecutive standards

4. Analogy with other energy sources

In this section, we discuss the analogy with the use of new energy source, as electrical cars, hybrid cars (gas+ oil) or (electrical+ oil). That means that instead of using radio spectrum for transmitting data, we may use wired connection, optical connections or other means which need to be discovered, etc. This section is equivalent to the discussion of section 3.2.2. It offers other indirect gains as less electromagnetic pollution**.**

The example of [2] given in Figure 2 is an example of the use of wired connections. The solution proposed by Greenair [6], which consists in using wired line backhaul in femtocell scenario, is another example.

5. Conclusion

The different analogies described in this paper show that to optimize the spectrum usage it is necessary to share its usage between users. The increase of the overall throuput to be transmitted is also questionable. Some analogies proposed in this paper would have some consequences for the ICT industry (consumer electronics, operators…). In fact, as for automobile industry (the number of classical cars will decrease), some choice will imply less boxes, but engineers have to imagine new equipments, have to think Green Radio communications.

Some other automobile solutions as, toll in downtown, oil price, car price depending on its CO2 emission,…have no analogy described in this paper. To pursue this analogy will allow finding other spectrum optimization ideas thanks to automobile domain experience.

To fill the examples given in this paper, Cognitive Radio is the perfect tool as already claimed in [3].

6. Acknowledgments

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