A NOVEL APPROACH FOR SIMULATING A BIO-CONTAMINATION PROCESS

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Abstract: The phenomenon of bio-contamination in a population of individuals being contaminated in a near by near physical, viral or bacterial contact could be compared by analogy with a near by near exchange of "atomic" data between mobile entities of an ad hoc network. Would the tools of wireless communication engineering then make it possible to contribute in the modeling of a bio-contamination process? Does the use of CSMA/CA in order to share the "contamination medium" make it possible to simulate this process of contagion? To establish the limits of the analogy, we consider the most unfavorable case, the systematic contamination of proximity. A susceptible mobile becomes contaminated if it passes near a contaminant mobile at a distance lower than the contamination distance. Simulations under NS2 highlight the effect of the overall radiation compared to the power used for emitting the atomic data representing the virus and reveal an optimal frequency of atomic data diffusion in the case of a population with strong geographical density moving in confined environment.

1 INTRODUCTION

The symbolic system and the vocabulary used in part(a) of figure 1 give the impression that it is an ad-hoc wireless communication system between entities moving according to a certain trajectory and a given speed. A mobile emits or receives information by means of an antenna characterized by the range of an electromagnetic radiation. This exchange of data takes place only if the receiver is within range from the transmitter, more precisely the distance traveled by the signal, is lower than a given threshold.

Let us suppose now that this range does not concern the distance at which the mobiles can exchange information but the distance of a contamination by air following a cough, a sneeze, or simply breathing, between individuals during an ordinary day. Part (b) of figure 1 shows that the entity A (the contaminant) contaminates the entities B then C which become in their turn contaminators.

The question put here is the following one: can the engineering of the wireless networking be usable to include (represent) a process of bio-contamination? More precisely, prototyping using light wireless communicating equipments, or simulating using simulators developed for the wireless communications like OPNET and NS2, can be of a certain utility to model a process of contagion?

The most important criteria that affect a contagion process identified by (Shane C. St. John, 1997) were:

- The probability of infection.
- The probability of recovery.
- The number of encounters between individuals which depends on: the density of the population and the dynamic degree of that population.
- The initial number of infected individuals.

Each one of these parameters can be associated with a step of the modulation process using simulation tools like OPNET and NS2 (G. Chalhoub, A. Freitas & M. Misson, 2007). Let us consider the probability of infection: a susceptible individual touched by a contaminant is considered infected with a probability of infection P. In the

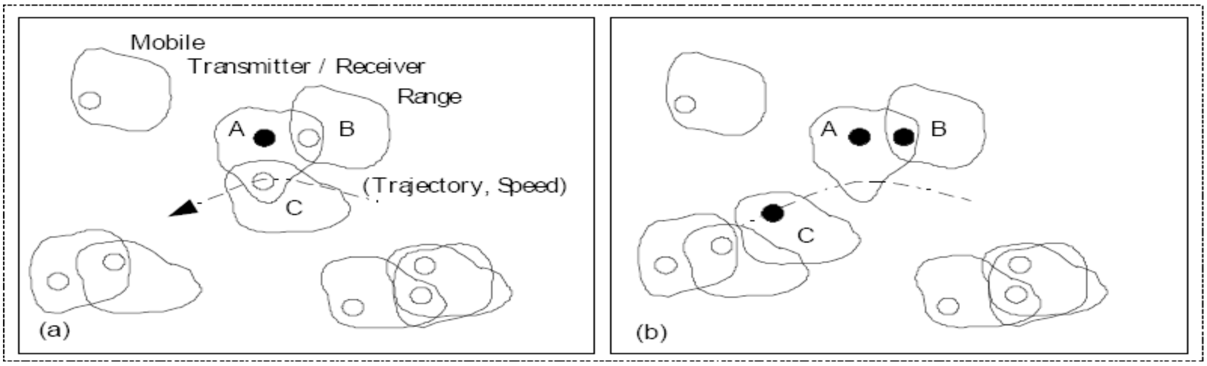

Figure 1: Wireless Communications / Bio-contamination process.

context of a network modulation process, the transition from susceptible to infected will not take place unless the susceptible individual receives a contaminant message with a certain probability of success (figure 2). In this article we are considering a systematic contamination (P=1).

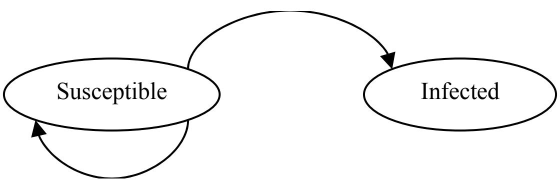

Figure 2: Susceptible becomes infected.

2 ASSUMPTIONS

If we consider the cough or the sneeze as means of contamination by air between individuals, the analogy with a wireless networking will result in the diffusion on the radio medium of a frame containing atomic data. Nevertheless, we make the assumption in this article that the contamination is regarded as succeeded, if this information is received with no errors by one or more other entities.

For an individual the support of viral transmission, the air, is always available. A cough or a sneeze of an individual can be contaminant even if other individuals have an activity which coincides in time at the same place. In that sense the activities of contamination are rather cumulative. Here we see a limit with our analogy arising. In a WLAN several simultaneous emissions cause a superposition of signals, a collision, which makes impossible the deciphering of information (with the exception of the capture effect). In this case, the contention-based access methods implement an arbitration which will try to order the access to the medium. Data to be transmitted will then undergo a random delay. The access method CSMA/CA is today the most “popular” method in the field of the WLAN (ANSI/IEEE Std 802.11, 1999), (IEEE Std 802.15.4™-2003)…, and will be detailed in part 3 of this article.

In the case of a contamination caused by coughing or sneezing, the recurrence of the events is about a few seconds. This recurrence is not really periodic but, nevertheless, we can consider it as a "Burst" activity like it is illustrated in figure 3. Although T_1 and T_2 are not periodic, the time t separating 2 messages in a "Burst" transmission can be considered as a pseudo periodic activity.

While transposing this activity in a wireless networking domain with the CSMA/CA method, the density of traffic representing the information of contamination will be easily assured by the MAC layer (G. Chalhoub, A. Freitas & M. Misson, 2007). This approach differs from the stochastic model based on the cellular automata used by (H. Situngkir, 2004).

This leads us now to consider a contamination only due to proximity. Any susceptible individual who is near a contaminated person, at a distance lower than the distance of contamination, becomes contaminant himself. We will call this model of contamination by proximity, the geometrical model.

In the context of wireless networking, the contaminated entity must broadcast atomic information of contamination. Our objective is thus to answer the following question: compared to the geometrical model, which is the optimal frequency of broadcasting the contamination data, with CSMA/CA as the access method, in a context of strong density of individuals and a contamination by proximity?

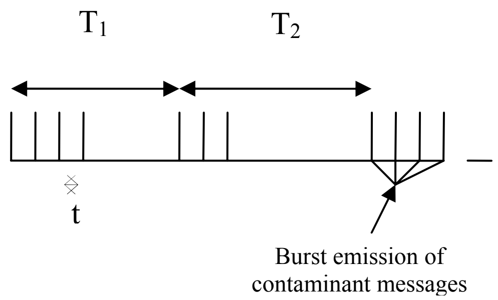

Figure 3: Burst activity.

3 CSMA/CA AND THE SHARED MEDIUM

The basic principle of CSMA consists in listening to the medium before emitting when a station has a pending (ready to be emitted) frame (Chen, 1994). On the discharge of the medium the station applies a method to manage the possible competition with other stations. In the case of the CA (Collision Avoidance) method the stations draw a back-off period to desynchronize the potential candidates.

The detection of an activity on the network is carried out by the measurement of the power of the received electromagnetic radiation. If this measurement is higher than the fixed threshold for the noise, the medium is regarded as being busy.

In the case of WiFi, the contention resolution mechanism is governed by the 802.11 standard specifications (ANSI/IEEE Std 802.11, 1999). For the DCF (Distributed Coordination Function) mode a station having a pending frame may begin to access only when the radio channel is sensed Idle. That is the case when the PHY layer performs a "Clear Channel Assessment (CCA)" which returns "IDLE" as the value of the CCA Indicator. This is the case when the energy level received is lower than a threshold very often estimated at - 95 dBm (value given by the suppliers of WiFi interface). It is this value which is passed in parameter (CSThresh: Carrier Sense Threshold) for a simulation by NS2 (Wu Xiuchao, n.d.) and which creates a little polemic for a simulation by OPNET (S. Roy, H. Ma, R. Vijayakumar & J. Zhu, 2006). Let us consider a signal received with a power Pr higher than the Carrier Sense Threshold, it allows to identify the fact that the channel is indeed busy but it is not a sufficient condition so that the information transported by the signal can be suitably interpreted. For that it is necessary that the receiver has a Margin of Decoding (MD) which depends on the modulation used for the transmission (Intersil Data Sheet HFA3861B, 2001). For example, it is admitted that in the case of a WiFi network the decoding of a frame with 11 Mbps requires that the energy of the signal received be higher than - 82 dBm. It is the value which is passed via the RXThresh parameter in a NS2 simulation. This obviously implies that the area in which the signal is perceived as higher than - 95 dBm is much larger than the zone of reception. If we illustrate that by a mechanism of contamination by cough simulated using an access method of the type CSMA/CA, a person who coughs prevents from coughing people whom it does not reach!

This is illustrated in the parts (a) and (b) of figure 4. The most external disc represents the surface in which the CCA indicator has the value BUSY, the disc delimited by -82 dBm corresponds to the surface in which the reception is done with an acceptable error rate.

Regardless of the nature of the medium, at a short distance from the transmitter, it is standard to consider that the law of dispersion of energy is in $1/D^2$.

If we know the transmission power, it will possible then to deduce the received power at the security (or contamination) distance which we introduced. Thus for a transmission power of 20 dBm the power hoped at 2 meters is - 26 dBm. It is what corresponds to the smallest disc of part (b) of figure 4.

In the same way by adjusting the power of transmission to -36 dBm, the threshold of reception of -82 dBm corresponds to the distance of contamination. This is represented by the part (c) of figure 4.

At this stage we can discuss the effect of the Clear Channel Assessment (CCA). A transmission with 11 Mbps and a power of - 36 dBm has an impact which goes well beyond a disc of 2 meters because of the CCA which covers a surface with a power higher than - 95 dBm. By reducing the power of emission we also reduced considerably the surface of carrier sensing. Using NS2 we will evaluate the effects of reducing the power of transmission, on the simulation of the process of contagion.

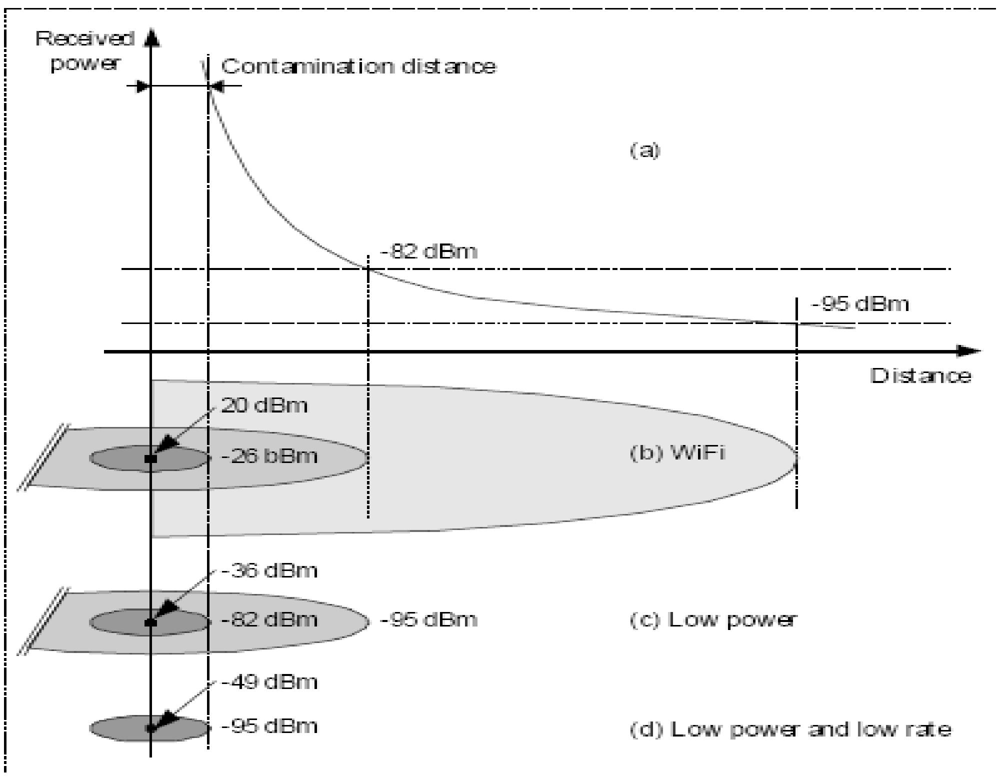

Figure 4: CSMA and thresholds.

4 SIMULATIONS

The object of this paper is to study if the choice of the access method CSMA/CA exploited to broadcast atomic information at a given frequency is an acceptable way to model a process of contamination by contact.

4.1 The Reference Taken for a Contamination by Contact

In our approach of simulation we considered that the ideal case was given by a geometrical approach of the problem, i.e. at any moment (in fact every 10 ms) we calculate for each contaminated station the distance which separates it from its neighbors. So if for a neighbor of a contaminant, this distance is lower than the threshold of contamination, this neighbor becomes also contaminated.

The choice of the frequency of this calculation depends on the velocity of the mobiles: the latter being at a maximum of 2 m/s this gives us a maximum error of 4 cm on the calculation of the distance between mobile if calculation is made every 10 ms. By this geometric calculation we obtain a number of mobiles contaminated throughout the simulation time that we will indicate thereafter like the result of the geometrical model. This result will represent an asymptote for those which are obtained by any other way.

4.2 The Simulation Assumptions

In this paper we chose to illustrate the results of a contamination modeled by CSMA/CA and to compare them with the results of the geometrical model for two configurations of mobiles which correspond to the same initial rate of contamination.

- The First simulation: 100 mobiles in a surface of 20 X 20m² with only one mobile contaminated at the beginning of simulation
- The Second simulation: 400 mobiles in a surface of 40 X 20m² with 4 mobiles initially contaminated.

In these two cases two frequencies of broadcasting (2 and 10 Hz) and two powers of transmission (20 and - 36dBm) are studied.

All simulations were made for 20 scenarios of nodes distribution and the curves displayed later on represent the averages of the number of nodes contaminated during these 20 simulations. Each simulation represents an evolution of the contagion during 20 s, the number of contaminated mobiles is calculated every 0,2 s. All nodes are randomly moving within the simulated area with a maximum speed of 2 m/s.

4.3 Analysis of the Effects of the Transmission Power

In the case of the first simulation one can note that the power of transmission does not have much influence because the curves obtained for 20 dBm and - 36 dBm are very close (Figure 5). The frequency of broadcasting at 10 Hz makes it possible to approach the geometrical model much more clearly.

While multiplying by 2 the geographical density of the nodes and by considering the same density of contaminant (4 nodes initially contaminated), a diffusion made with a limited power gives results that approach more the geometrical model than those done using the usual power of Wifi.

The simulation results:

With our assumptions everything takes place during the first seconds of simulation. Figure 6 shows clearly how reducing the transmission power improves the propagation by reducing the effect of CSMA/CA on the delay of the diffusion in an area with a dense population.

4.4 Examining the Effects of the Frequency of Diffusion in Low Power Transmission

Another factor which has also a big part in determining the effect of CSMA/CA is the frequency of diffusion. Our goal is to approach the geometric model which gives us a representation of an almost continuous contagion. Hence, one can think of increasing the frequency of the broadcasting of the contamination frames, that means increasing the offered load on the network and reaching the limits of the effectiveness of such an access method (Chen, 1994). We can thus suppose that there exists, for a given density of mobile stations, an optimum frequency of transmission, and that's what we will try to find by simulation.

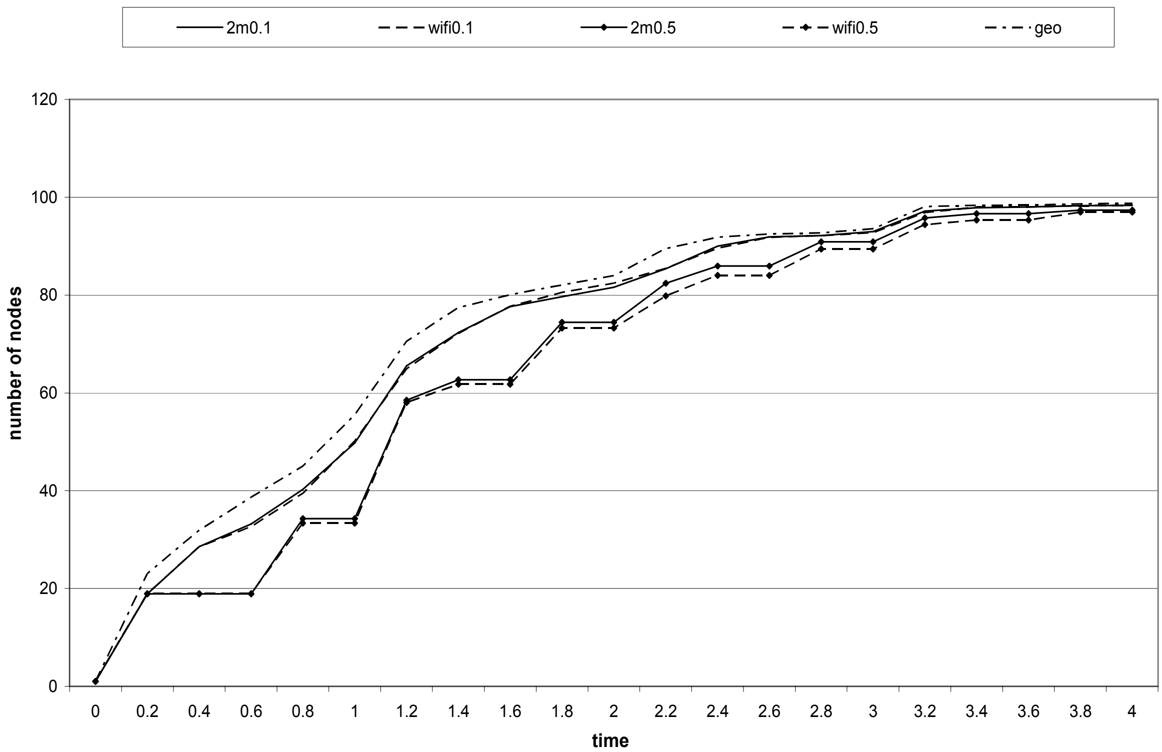

Figure 5: Low density contamination.

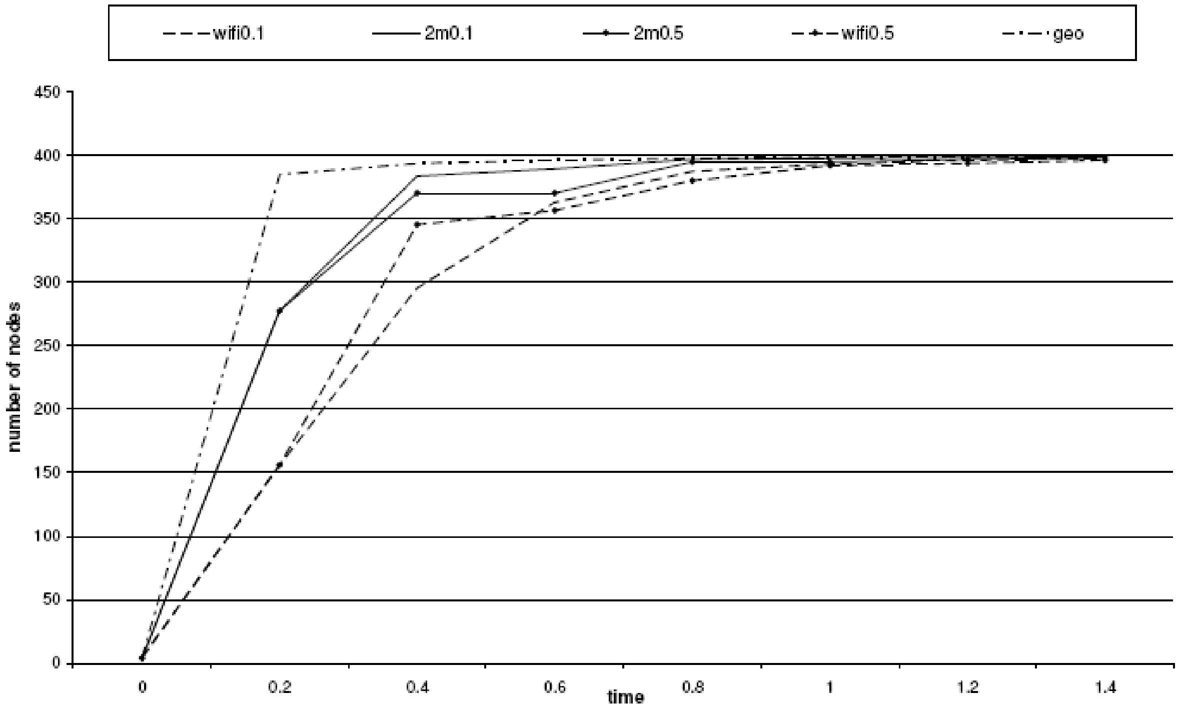

Figure 6: High density contamination.

We tested several frequencies using the previous model by using a low power transmission (- 36 dBm). For frequencies of broadcasting going from 0.5 to 200 Hz, we will consider the average of 20 simulations, to calculate the number of contaminated nodes. Each simulation lasts 20 seconds and gives a value every 0,2 second, we will thus have 100 values per frequency. These 100 values will be compared with those corresponding to the same moment, given by the geometrical model to identify a difference: "an error" between the theoretical contamination given by the geometrical model and that approached by CSMA/CA.

Let M be the average of these 100 differences between the two corresponding values for each frequency of transmission, we thus obtain the following curve (Figure 7):

We can notice that with a frequency of diffusion between 10 and 20 Hz the average number of contaminated nodes is 0.5 node less when compared to the ideal number given by the geometric model. We can clearly identify 3 different zones illustrated by that curve. In the first zone we are under-loading the network using frequencies between 0.5 and 4 Hz for emitting contaminant messages and not being able to produce the same result given by the geometric model, which is easily explained by the fact that we are missing some encounters due to the mobility of the individuals that cross into each other without being able to exchange contaminant messages. By increasing the frequency beyond 20 Hz we are overloading the network and the effect of CSMA/CA causes a delay on the transmitted messages which prohibit some individuals to emit and therefore miss some encounters. We determined effectively an optimal frequency of diffusing contaminated messages in a continuous way which, for our assumptions of simulation, varies between 10 and 20 Hz.

5 CONCLUSION AND PERSPECTIVES

CSMA/CA and simulators for the wireless networks are original assets to simulate processes like a contamination by contact. We have just shown that by adjusting the transmission power and the frequency of the access to the medium, it is possible to simulate with a simulator like NS2 the way in which a virus is propagated in a mobile human being community.

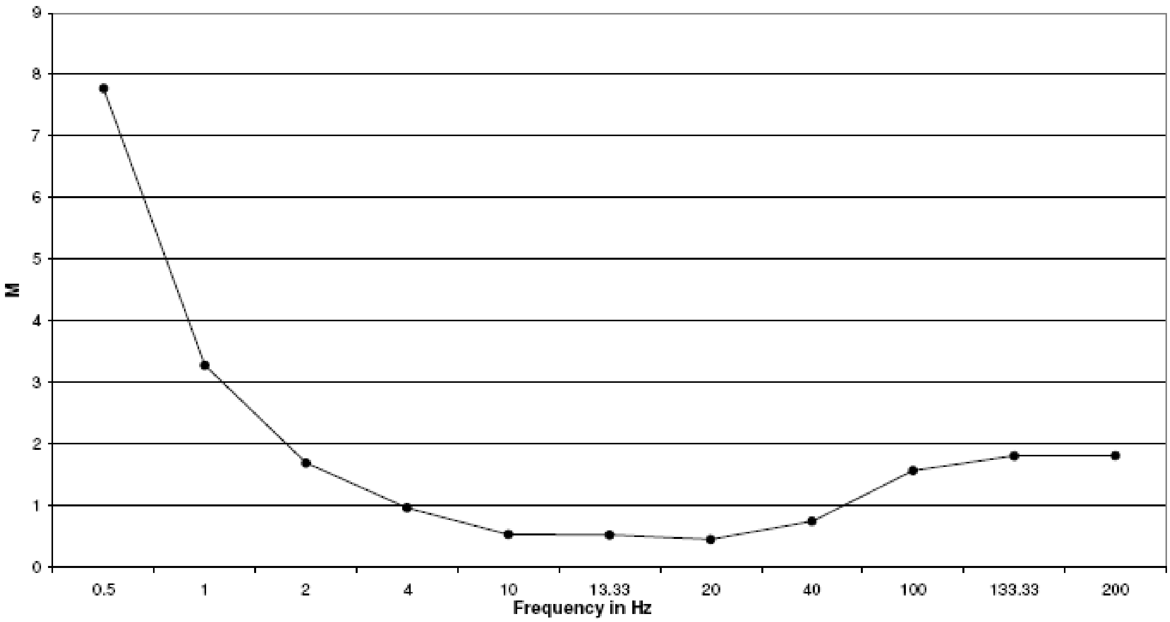

Figure 7: Frequency effect.

To approach more the real nature of a contamination by proximity, the action of the contaminant radiation of a node must be limited to the distance of contamination. It would be interesting to study next the effect of the bandwidth which finishes the surfaces dilemma between the zone of carrier sensing and that of a good reception. In the case of a 1 Mbps transmission these two surfaces are overlapping which brings us even closer to the geometrical model (part (d) of figure 4).

Following a meeting, that took place June 2007, with a group of doctors who were interested in our work, we will improve our simulation model by defining individual profiles which define the personal biological characteristic of each individual (degree of vulnerability, being immunized or not, and time needed to be recovered…), and by applying the "burst" activity to emit the contaminant messages instead of the continuous emission. Having a virus profile with all its characteristics will also help us build a specific transmission behavior that will reproduce the virus' nature.

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