

# Predicting data rate coverage using the Sabine Method in multiple-source hospitals today and tomorrow

Christopher W. Trueman<sup>a</sup>, Sergio S. Muhlen<sup>b</sup>, and Bernard Segal<sup>c</sup>

<sup>a</sup> Dept. of Electrical and Computer Engineering, Concordia University, Montreal, Canada

<sup>b</sup> Dept. of Biomedical Engineering, UNICAMP, Campinas, Brazil

<sup>c</sup> McGill University and SMBD Jewish General Hospital, Montreal, Canada

## Abstract

In the future, many hospitals will install wireless local area networks (WLAN) to allow medical staff to access patient records freely from any location, in the presence of perhaps thousands of other wireless sources and in many reflective environments. The Sabine method provides a framework to facilitate this process with relatively little computational effort, because the method considers local volume-average fields, rather than fields at a point. This method is illustrated by showing how an IEEE 802.11b WLAN can be installed in a paediatric intensive care unit (PICU), using several access-point antennas on each channel to achieve a high data rate at most locations. The Sabine method is used to estimate the field strength of each access-point antenna over the PICU floor plan, and in turn to assess the possibility of interference with medical devices. The field-strength estimate is used to find the signal-to-interference ratio for each antenna on each channel over the floor plan, and in turn a channel model is used to estimate the data rate for communication on that channel at each location. Relatively high data rates are possible. A similar design effort is applicable even in the multi-source environment of future hospitals.

**Keywords:** indoor propagation, wireless local area network, electromagnetic interference, data rate, multiple sources

## Introduction

There is an increasing need for wireless information in hospitals to improve staff communication (voice, etc.), to provide medical staff with patient information, to monitor patient and equipment-status data, and to provide location information about staff, patients and medical devices. To meet these growing information requirements, more and more wireless sources will be deployed, potentially reaching hundreds of thousands of sources in future hospitals. Methodologies are required that will permit such sources to operate at maximal throughput without causing interference to life-supporting medical equipment. The Sabine method can help achieve this more easily because it is based on volume-averaged fields, rather than on fields at a point in space. This paper will illustrate how this method can be used to deploy an 802.11 system of increased throughput, while observing interference limita-

tions. The advantage of this approach is the overall effects of operating multiple additional wireless sources is readily predicted and accounted for.

This paper considers the design of a wireless local area network (WLAN) to serve the paediatric intensive care unit of Figure 1. There is a ten-bed ward, a lactarium, a drug preparation area, a patients' reception, a nursery post, and small rooms such as toilets and closets. The objective is to provide a high data rate at any location over the whole floor plan,

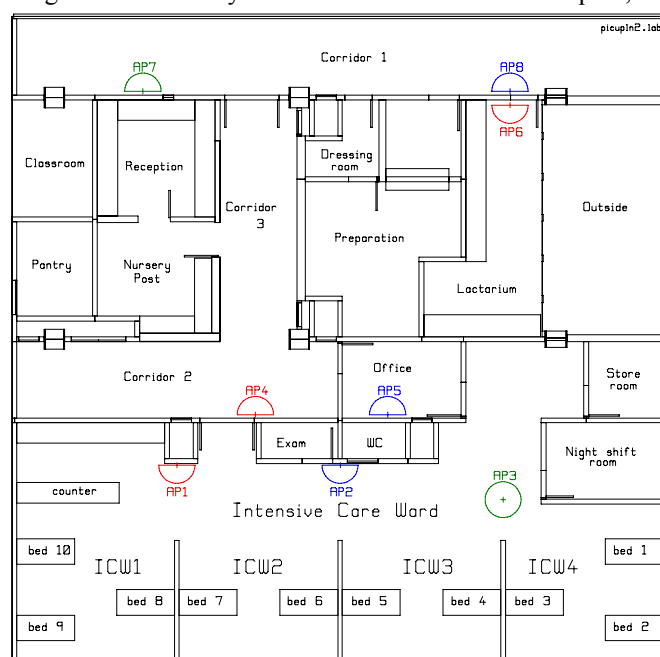


Figure 1 - Floor plan of a 360 m<sup>2</sup> Pediatric Intensive Care Unit showing the placement of the access-point antennas.

using the IEEE 802.11 b or g standard. In this paper, the WLAN will be designed by assessing the coverage of each access point antenna (AP) using the Sabine method. The potential for EMI with medical devices will be assessed by examining the net signal strength of the APs over the floor plan and comparing with the immunity level. As many as three APs will be used on each channel, hence there will be interference. The field strengths computed with the Sabine

method will be used to compute the signal-to-interference ratio (SIR) for communication with each AP at each point in the floor plan. A simple additive white Gaussian noise (AWGN) channel model is used to determine the data rate as a function of the SIR and hence to estimate the data rate for each channel at each point over the whole floor plan. Adding the data rates for the three channels provides a measure of the quality of the WLAN installation over the whole floor plan.

### The WLAN Design

The IEEE 802.11b or g standard provides three channels that do not overlap in frequency: channel 1 centered at 2412 MHz, channel 6 at 2437 MHz and channel 11 at 2462 MHz. Under ideal conditions, a data rate of 6 megabits per second (Mbs) can be supported by one AP antenna. The desired overall data rate for the PICU WLAN is 40 Mbs, so at least 7 access point antennas are needed. This was increased to eight to provide some over specification in the design. Three antennas will operate on channel 1, three on channel 6, and two on channel 11. Antennas on each channel should be sited so that their coverage areas do not overlap. Coverage is assessed using the Sabine method, as follows.

### The Sabine Method

The Sabine Method [1,2] provides a simple estimate of the spatially-averaged electric field strength  $\tilde{E}_{mean}$  of an antenna operating in an indoor environment, as

$$\tilde{E}_{mean}(r) = \sqrt{\frac{\eta DP}{4\pi r^2} + \frac{4\eta P}{A_{in}}} \quad \dots(1)$$

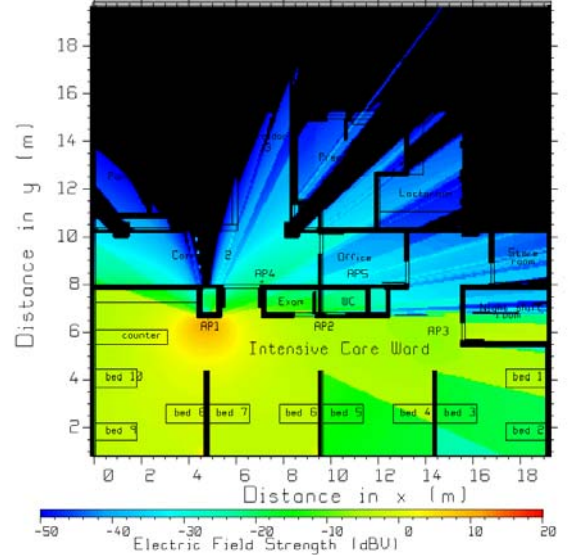
where  $r$  is the distance between the antenna and the observer,  $D$  is the directive gain of the antenna in the direction of the observer,  $P$  is the radiated power, and  $\eta$  is the intrinsic impedance of space. The room is characterized by its “indirect absorption”  $A_{in}$  given by

$$A_{in} = \frac{AS_T}{S_T - A} \quad \dots(2)$$

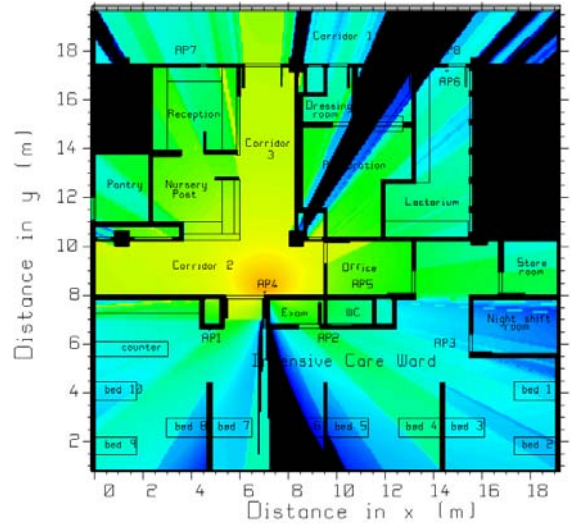
where  $S_T$  is the surface area of the walls, floor and ceiling, and  $A$  is the Sabine room absorption given by

$$A = \sum_{k=1}^N S_k \tilde{\alpha}_k \quad \dots(3)$$

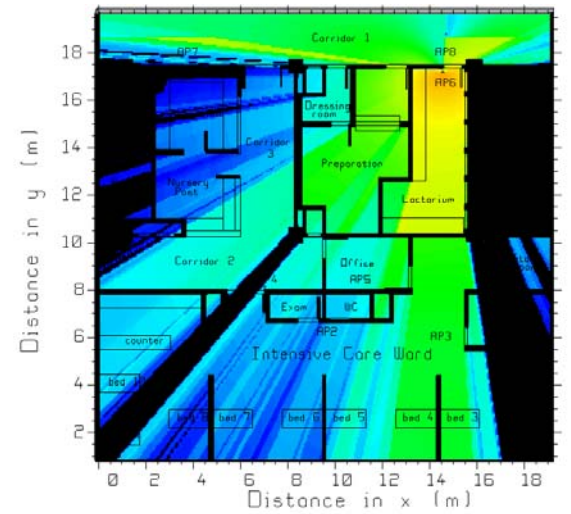
The number of different surfaces in the room is  $N$ , and the area and angle-averaged power absorption coefficient [2] of the  $k$ -th surface is  $S_k$  and  $\tilde{\alpha}_k$  respectively. Ref. [1] compares field strengths computed with the Sabine method to measured field strengths, with reasonable agreement.



(a)



(b)



(c)

Figure 2- Coverage maps showing the electric field strength distribution for AP1, AP4 and AP6 on channel 1.

In a large, open space the room absorption is large and the contribution of the room to the field strength in (1) is small; the environment approximates free space. Conversely in a small room the absorption is small and the second term in (1) contributes a substantial field strength.

The Sabine method is generalized to apply to complex floor plans in [3]. In evaluating (1), when the ray from the source to the observer passes through a wall, the field strength is reduced by the angle- and polarization-averaged transmission coefficient. In adjacent rooms the power that is transmitted through the wall is estimated to evaluate the room contribution. But if the source and observer are separated by more than two walls, the room contribution is omitted.

## Coverage Maps

Figure 2 shows coverage maps, computed with the Sabine method, for AP1, AP4 and AP6, which all operate on channel 1. The AP antennas are mounted at the ceiling height of 2.25 m and the coverage map is computed at a height of 1.6 m above the floor. Each AP radiates 100 mW at channel 1's frequency of 2412 MHz. The directional patterns of the antennas are shown in Figure 1. Fig. 2 gives the field strength in dBV, that is, dB relative to 1 V/m field strength.

Each antenna should cover a sector of the floor plan with sufficient field strength for a high data rate in the absence of interference. Ideally, the area each antenna covers should not overlap that of the other antennas on the same channel, so that the antennas will not interfere with one another. AP1 is a directional antenna with a 180-degree pattern, and Figure 2(a) shows that AP1 covers the west end of the intensive care ward, with low field strength in the corridors behind the antenna. Figure 2(b) shows that AP4 covers the west end of the north half of the PICU, illuminating the two corridors, and the reception and nursery areas. Part (c) shows that AP6 covers the lactarium and preparation areas, but also that the field "leaks" through the wall into the east end of the ward, and so will interfere with the field of AP1.

## EMC Considerations

In operating a WLAN in a hospital environment, there is the possibility of interference with critical-care medical devices, if the field strength exceeds the immunity of such equipment. Newer medical devices have an immunity of 10 V/m (20 dBV) or higher, but older devices often have an immunity as low as 3 V/m (9.54 dBV), or lower [4].

The spatially-averaged value of the electric field strength, or "mean value field strength", at the frequency of channel 1 can be estimated by combining the field strengths of AP1, AP4 and AP6 on an energy basis according to

$$\tilde{E}_{net} = \sqrt{E_1^2 + E_2^2 + E_3^2} \quad \dots(4)$$

The mean-value estimate of (4) is simple to calculate from the data of Figure 2, and is shown in Figure 3. There is a "hot spot" directly under each AP antenna. Over a small region, enclosed by a black contour in Figure 3, the field strength exceeds 9.54 dBV, the immunity of older medical devices. But because the map of Figure 3 is computed at a height of 1.6 m and the APs are mounted at 2.25 m, a separation of 65 cm is maintained and the field strength never approaches the immunity level of newer equipment of 20 dBV.

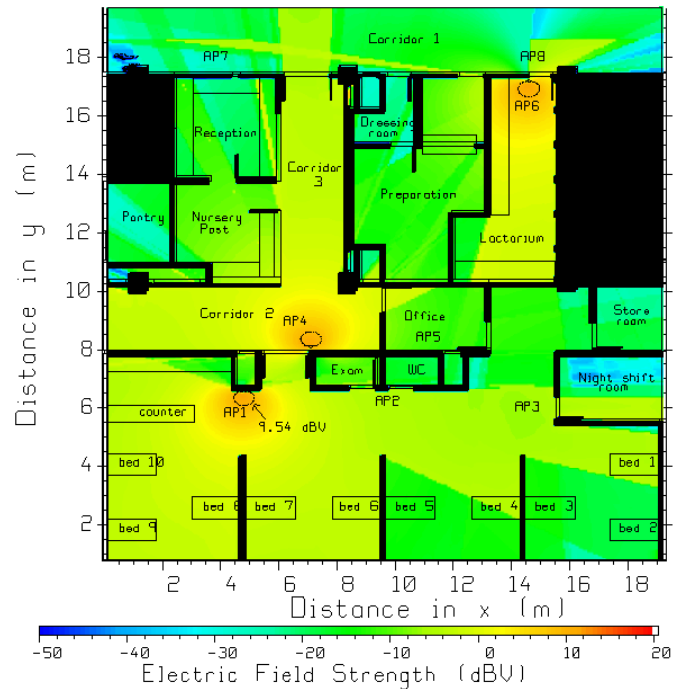
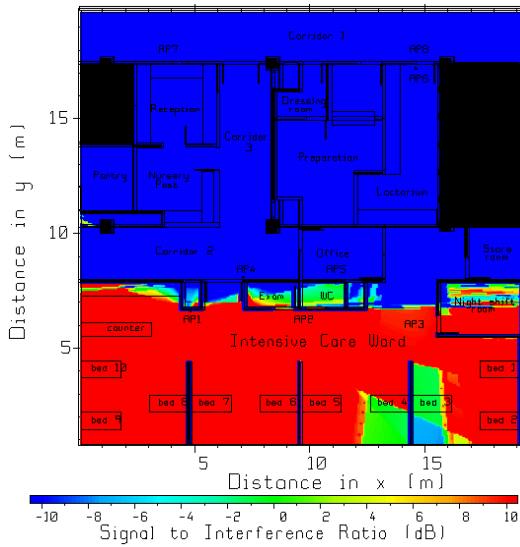


Figure 3 - The net field strength of the three antennas on channel 1.

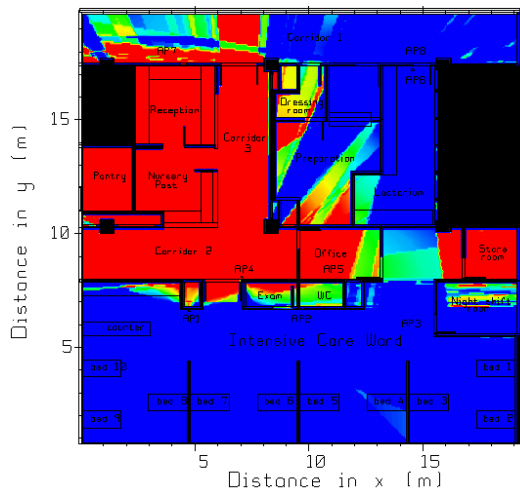
In interpreting the mean-value field map of Figure 3, recall that the actual field strength varies randomly around the mean value, with a Rician probability distribution. Thus, at individual locations, the field strength may be considerably larger than the mean value of Figure 3 and immunity may be exceeded. Also, in operating the WLAN, medical personnel carry hand-held wireless transmitters, which are 100 mW sources and their fields can be a source of EMI. This is often dealt with by instructing the staff to maintain a minimum separation [4] between the handheld transmitter and medical devices. For a 100 mW transmitter operated near a medical device of immunity 10 V/m under free space conditions, a minimum separation of 100 cm is safe.

## Signal-to-Interference Ratio

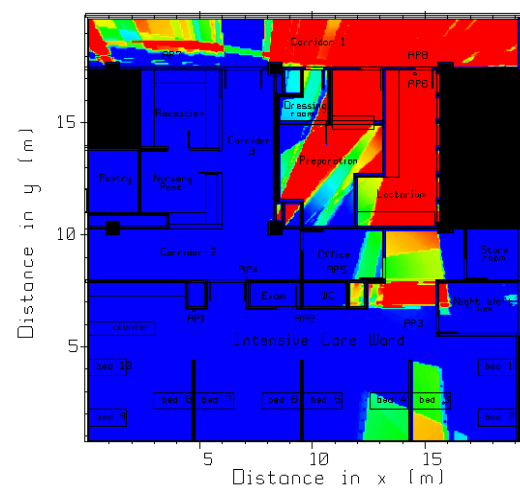
The SIR is readily computed using the coverage maps of Figure 2. Thus, for AP1 the "signal" is the field strength of AP1, and the "interference" is the field strength of AP4 and AP6, combined on an energy basis, and the SIR map is shown in Figure 4(a). AP1 has an excellent SIR, approaching 10 dB,



(a)



(b)



(c)

Figure 4 - Signal-to-interference (SIR) maps for AP1, AP4 and AP6 operating on channel 1.

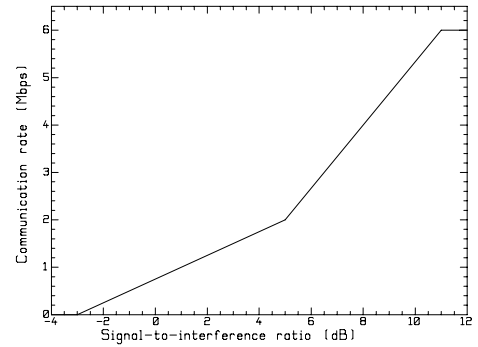


Figure 5 - The data transfer rate as a function of the signal-to-interference ratio.

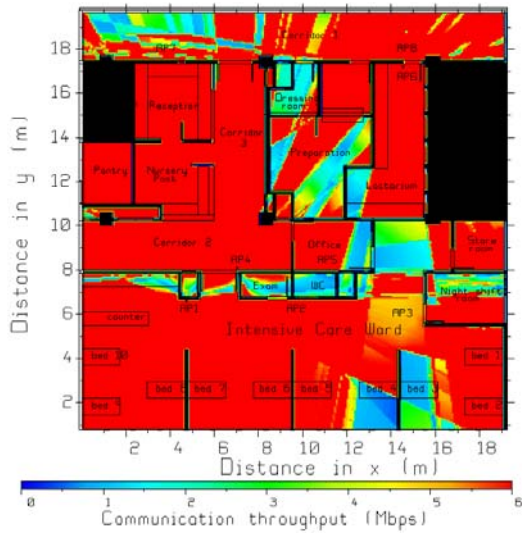
over most of the intensive care ward, except for small regions near bed 3 and bed 4, where there is interference from AP6. Part (b) shows that AP4 maintains an excellent SIR over the areas that it is intended to cover, as does AP6 in part (c). Note that the region around bed 2 and bed 3 has a poor SIR for all three antennas, and communication on channel 1 will be poor in this area.

### Data Rate

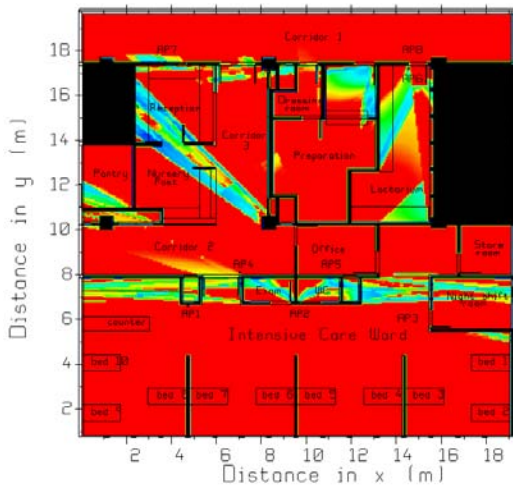
The AWGN model of a channel relates the rate of data transfer to the SIR. For the hardware to be used in the PICU, the SIR-to-data-rate transformation is assumed to be approximated by the relationship in Figure 5. The relationship can be used to create a map that shows the speed of communication expected at each location in the floor plan for each channel. Thus, the SIR maps of Figure 4 can be transformed to data rate maps for each AP antenna on channel 1. Then at each point in the floor plan, take the highest data rate, to obtain the data-rate map of Figure 6(a) for channel 1.

The map shows the best data rate obtainable at each point in the floor plan on channel 1, but does not indicate which of AP1, AP4 or AP6 supports communication at that point. Thus, as expected, the high SIR values for the individual antennas over their coverage areas lead to high data rates, but where the SIR is poor the data rate is slow. For example, the area around beds 2 and 3 has a poor data rate because the signals of AP1 and AP6 interfere with one another.

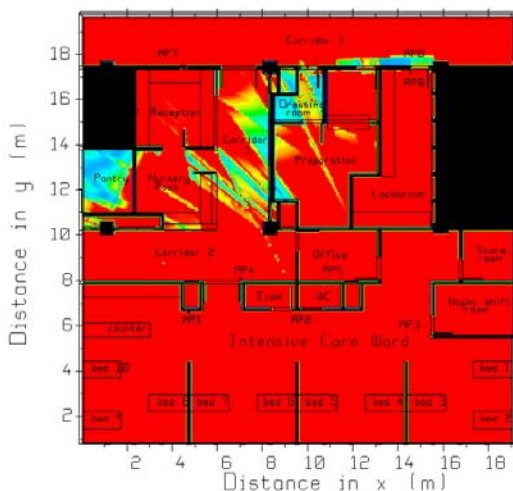
Coverage maps are readily computed for AP2, AP5 and AP8 on channel 6, leading to SIR maps, and then to the net data-rate map of Figure 6(b). The data rate expected over most of the floor plan for channel 6 is very high. There is some interference in corridor 2 and the reception room, and the lactarium. The data rate map for AP3 and AP7 on channel 11 is shown in Figure 6(c). For channel 11, which is supported by only two antennas, there is interference in corridor 2 as well, but communication in corridor 2 is well supported on channel 1. Note that both channels 6 and 11 support high data rates at bed 2 and bed 3.



(a)



(b)



(c)

Figure 6 - The data rate expected on channel 1, channel 6 and channel 11 for the WLAN design of Figure 1.

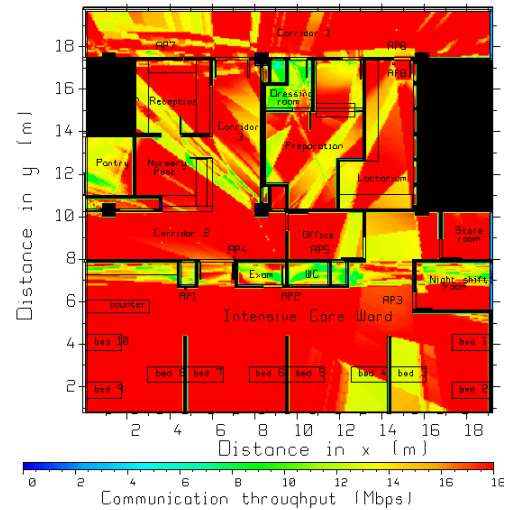


Figure 7- The net throughput of the WLAN over the floor plan. (Note different throughput scale in Fig. 6 and 7.)

The data rates of Figure 6 can be added to provide a net data rate at each point in the floor plan. Thus if three medical staff each use a handset to communicate with the WLAN at a given location, each handset will “choose” a different channel, and over much of the floor plan, each will communicate at 6 Mbps. Regions of the floor plan with interference on the individual channels in Figure 6 lead to a lower net data rate in Figure 7, for example in corridor 2 and near beds 2 and 3. The net throughput map of Figure 7 is a measure of the quality of the WLAN design of Figure 1. An excellent design would have a throughput of 18 Mbps (color red) at every location over the whole floor plan.

Adding additional APs may not improve data rates, because there may be more overlap of coverage areas leading to reduced SIR, causing a reduction in the throughput. If thousands of other wireless sources were also present, the Sabine method could be used to determine their effect on the average room field, and the resultant effect on the SIR.

## Conclusion

The Sabine method is well suited to multi-antenna environments such as WLAN design, because fields of each antenna can be evaluated rapidly over the whole floor plan. The indoor environment is accounted for through the room absorption. The field strength estimates are used in this paper both to assess the possibility of interference with medical devices, and also to assess the rate of communication achievable at each location over the whole floor plan. Various placements of the AP antennas and channel assignments can be considered to choose a design for the WLAN which achieves a high data rate over most of the floor plan. Effects of large numbers of wireless sources can be estimated via their effect on average room field. This capability will be useful in future hospitals where hundreds of thousands of wireless sources will operate.

## Acknowledgments

The authors gratefully acknowledge the support of PROMPT, Bell Canada, Nortel, FQRNT, and National Science and Engineering Research Council of Canada.

## References

- [1] Trueman CW, Davis D, Segal B, Muneer W. Validation of fast site-specific mean-value models for indoor propagation", *J App Comput Electromag Soc.* 2009, to be published.
- [2] Holloway CL, Cotton G, McKenna P. A model for predicting the power delay profile characteristics inside a room", *IEEE Trans Vehic Technol.* 1999; 48(4): 1110-1119.
- [3] Trueman CW, Muhlen SS, Davis D, Segal B., "Field strength estimation in indoor propagation by the Sabine method", in *Proc. 24<sup>th</sup> Ann. Review of Progress in Applied Computational Electromagnetics.* Niagara Falls, Ontario, Canada: ACES 2008; pp. 876-881.
- [4] International Electrotechnical Commission, *Medical electrical equipment, Part 1-2: General requirements for safety - collateral standard: electromagnetic compatibility-requirements and tests.* Arlington: ANSI/AAMI/IEC 60601-1-2, 2001.

## Address for Correspondence

Prof. C.W. Trueman, Dept. of Electrical and Computer Engineering  
Concordia University, 1455 de Maisonneuve Blvd. West. Montreal,  
Quebec, Canada, H3G 1M8