Contactless Power Line Communications at 2.45GHz

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***Abstract* — In this paper it is shown how a power line can be used to conductively carry and re-radiate 2.45GHz Wi-Fi signals over a distance. This can be useful when a conventional RF links' line-of-sight operation at 2.45GHz is obscured for example in multiple story buildings where Wi-Fi has difficulty penetrating. Commercial Wi-Fi modems were used to transfer data on a power line for up to 65m (non-energised) and up to 20m in a typical industrial energised situation. One modem was coupled to the power line, the line used as a travelling wave antenna and the second modem used in normal RF mode. This was compared to a direct RF link - where both modems were used in RF mode. Although a RF link performs better at long distances, with line of sight or few obstacles, the contactless power line configuration compared well in performance for a distance of up to 40m.**

Keywords—Contactless PLC, Power Line Communications, Wireless PLC.

I. Introduction

It is envisaged that with the *Internet of Things* [1] and the *Smart Grid* [2], connectivity between electrical products and systems will rapidly increase. Power line communications aim at utilizing electrical power cables simultaneously as a means of supplying power and as an electronic communications channel. This have several advantages over the situation where power and communication between products and systems are supplied separately, which lead to extra complexity and cost.

Conventionally Power Line Communication (PLC) is used between two fixed systems such as two computers connected via the grid or a sensor connected to a controller etc. [3]. This is opposed to systems where a radio frequency (RF) link supplies communication. With RF link systems (such as Wi-Fi), freedom of movement is ensured.

In this paper a configuration is described that uses the power line as a traveling wave antenna [4] for communications at 2.45GHz (IEEE 802.11g protocol). To this end, two commercial Wi-Fi modems were used to establish communication between two personal computers. One modem was coupled to the power line (fixed) while another was used in RF mode (mobile) to connect to the line now acting as an antenna. This configuration can be very useful in situations where line of sight is obscured and direct link RF communication is impaired. For example inside buildings with walls or between floors.

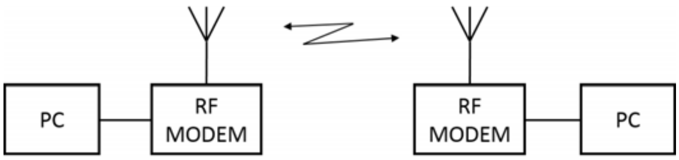

Fig. 1 - Set up for the direct RF-link

The contactless PLC described in this study is similar to previous work by de Beer *et al.* [5], but in this case the frequency is not up to 30MHz, but around 2.45GHz.

Although 2.45GHz has been investigated before for PLC usage and was conceptually proven in [4] and [6], this study gives actual transfer rate performance measurements in an industrial and ideal setting.

In this study, traveling wave contactless PLC is compared to direct link RF communications. It is shown that at long distances, direct RF links performs better than contactless PLC, but at shorter distances (typically up to 40m), contactless PLC is comparable in performance to the direct RF link.

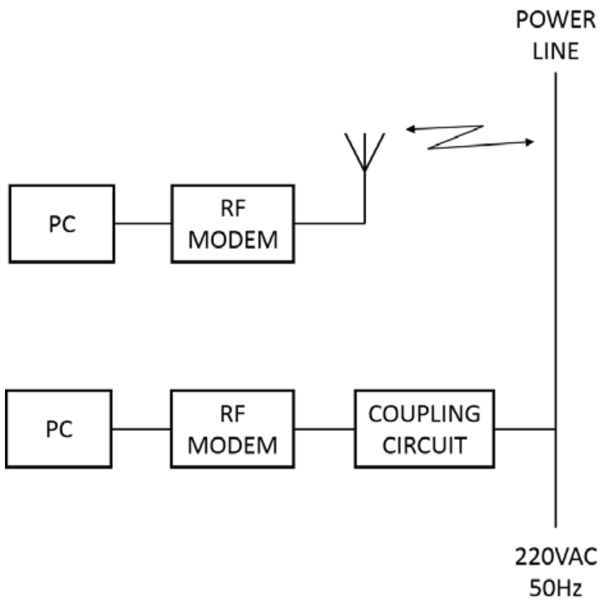

Fig. 2 - Set up for the Traveling Wave Contactless PLC

In this paper, two experimental set-ups are described. One is a typical industrial setting inside a building and the other is a best case free standing power line configuration. In both cases experimental results are given for a direct RF link (Figure 1) as opposed to a traveling wave contactless PLC set-up (Figure 2).

As the contactless PLC set-up needs a connection between the power line and RF modem, a coupling circuit was used. Although not the focus of this paper, some detail of the coupling circuit is given.

II. EXPERIMENTAL SET UP

Two configurations were used for the experiments in this paper. They are the RF-link and the Traveling Wave Contactless PLC. Both of these configurations were applied in two settings – an industrial building and a best case free standing power line configuration.

A. RF-Link

The RF-link consists of two identical systems comprising a personal computer (PC) and commercial Wi-Fi RF modem each (Figure 1). The modems are each equipped with an antenna tuned at 2.45 GHz.

B. Traveling Wave Contactless PLC

The Traveling Wave Contactless PLC configuration is shown in Figure 2. A free-standing PC and RF modem with dedicated antenna is the first and mobile part of the system. This is the same as one part of the RF-link configuration of Figure 1. Of importance here is the distance between the modem antenna and the power line. For this study a distance of 0.5m was used between the power line and the modem antenna.

The second part of the Traveling Wave Contactless PLC configuration shown in Figure 2 is a PC, modem and coupling circuit. Instead of an antenna the RF port of the modem is connected via a coupling circuit to the power line. This part of the system is fixed.

Detail of the coupling circuit is given in Figure 3. Instead of a conventional coupling circuit that uses capacitors and transformers a microwave configuration was used. This was done as capacitors and transformers have parasitic components rendering them ineffective at 2.45 GHz. Capacitors for example have Equivalent Series Inductance (ESL) effectively blocking microwave frequencies. Transformers on the other hand have inter-winding capacitance, short circuiting microwave frequencies and rendering the isolation properties of transformers ineffective.

The coupling circuit used was a stripped piece of RG-58 co-axial cable in proximity to the power line. The stripped section of the co-axial cable exposed a quarter of a wavelength of the inner conductor. The length of the quarter section was calculated to be:

$$\frac{\lambda}{4} = \frac{1}{4}\frac{0.65c}{2.45GHz} = 20mm \qquad (1)$$

Where c is the speed of light and the relative speed of propagation in a RG-58 co-axial cable was taken at 65%.

The exposed co-axial cable acts as a resonating quarter wave antenna radiating maximum power onto the power line. Although this configuration might not be optimal it yielded good results and can be further investigated in future work.

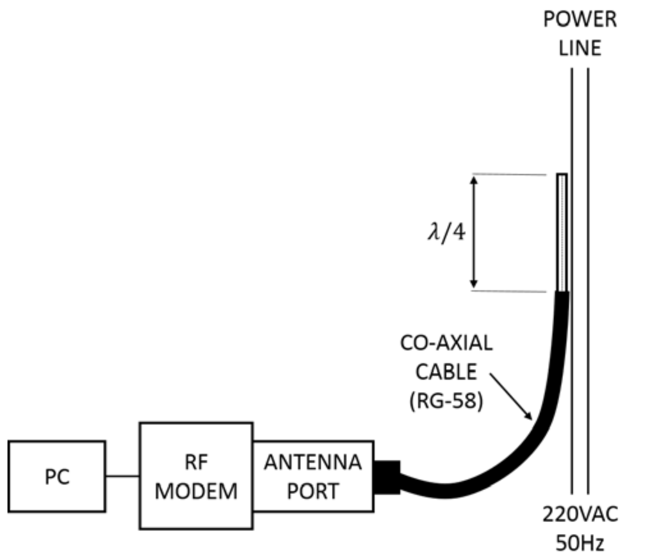

Fig. 3 – Detail of the coupling circuit for the Traveling Wave Contactless PLC

C. Troughput Measurement

In order to gauge the effectivity of the communication link, data transfer rate or throughput was measured between the two PC's. Local Area Network (LAN) software was installed on each PC. The purpose of this software is to upload or download a file to or from a PC and measure transfer time. The time it took to transfer a file of random data was logged and given the file size, a throughput rate in Mbps was calculated. During the experiments a file size of 20MB was used each time.

Data was transferred in two directions. From a "main" PC to another (downloading) and from the other PC to the "main" or uploading. These directions will further be clarified under the *Experimental Results* heading.

Measurement of the transfer rate did not give consistent results. Because of this, each transfer rate was measured several times and therefore the results show a spread of throughput rates.

III. EXPERIMENTAL RESULTS

In this study, measurements were taken in two physical settings. The first was a typical industrial building where the transfer rate of a RF link was compared to a contactless PLC set-up on the live installed power grid. The second was an off-line control where the contactless PLC (connected to a non-energized free standing cable) was compared to a RF link.

A. Industrial Setting

Figure 4 shows the floorplan for “B4 LAB Level1” which is the building at the University of Johannesburg that was used to measure contactless PLC and compared to a RF link. A 10m section is indicated for scale. For the contactless PLC measurements, a PC and modem’s signal was injected at “0” in Figure 4. This was done with the method shown in Figure 3. For direct link RF measurements, the PC at “0” was stationary and communicated in normal wireless fashion (Wi-Fi) to positions “A” to “F”.

The PC at “0” was deemed to be the “main” and data was *downloaded* to a second PC at positions “A” to “F”. Data was also *uploaded* from the secondary “A” to “F” positions to the “main” PC at “0”.

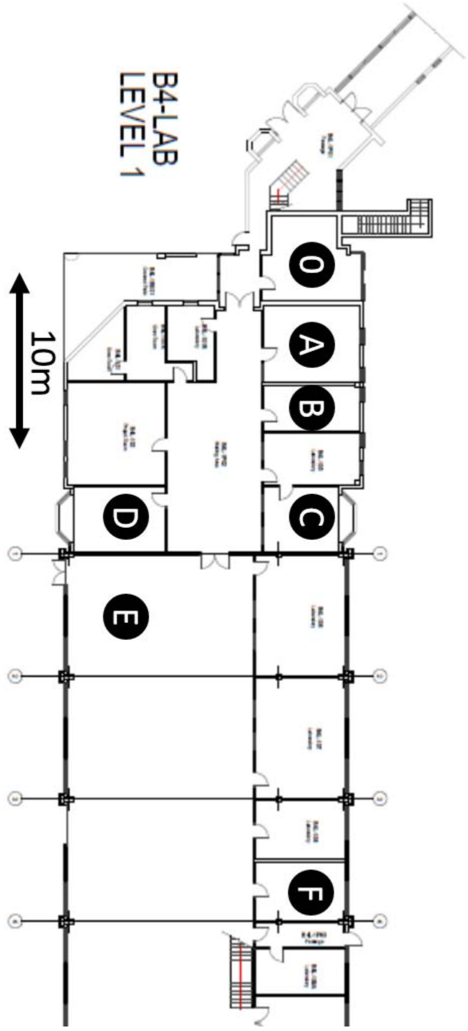

Fig. 4 – Building plan and positions for the measurements in an Industrial Setting.

1) Contactless PLC

Figure 5 shows data transfer rates to different positions in the building of Figure 4 – using contacles PLC across the live installed powerline wiring. At each position the secondary PC, modem and antenna were positioned roughly in the middle of a room (except for “E”). Position “E” was in an open laboratory space as indicated in Figure 4.

The first set of data points at “0” shows transfer rates for the secondary PC in the same room as the “main”. A difference in the upload and download rates is obsererved. This might be due to direct interaction between the coupling circuit and secondary PC modem antenna in the same room and that the powerline is not activated as antenna yet.

At positions “D” and “F”, the signal was too low to iniate communications.

Figure 5 should be compared to Figure 6, which is for the same building but RF links.

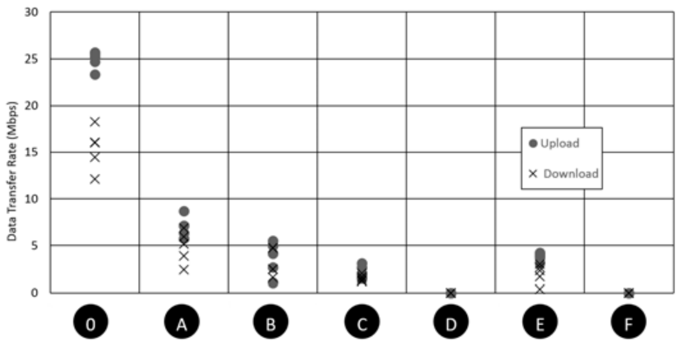

Fig. 5 – Data transfer rates to different positions in the building of Figure 4 – using contacles PLC.

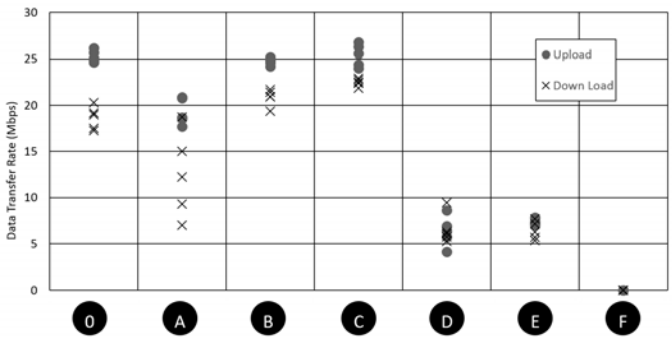

Fig. 6 - Data transfer rates to different positions in the building of Figure 4 – using RF links.

2) RF Link

Figure 6 shows data transfer rates to different positions in the building of Figure 4 – using RF links. At position “0” the results in Figure 6 are comparable to that of Figure 5. Position “F” was out of range but communication was esthablished for positions “A” to “E”. The data transfer rates for positions “A” to “E” are generally higher for the RF link than the contactless PLC. This represents an idealized or near to upper bound situation with only soft board partitioning as obstacles. Note that many buildings have concrete or brick and mortar walls. In fact it is well known that WiFi frequencies have difficulty to penetrate through to different floors in a multistory building where Power Line Communications can offer a solution.

B. *Free Standing Cable*

From the previous section it is clear that 2.45GHz Wi-Fi can be conducted on power lines inside a building. To further study this effect a "best case" control was set-up and measured. This comprised of a free standing (non-energized) power cable with a signal directly injected from the RF modem and a free standing RF modem with antenna, 0.5m from the cable. Again, this was compared to a line of sight direct link RF configuration (Figure 1). It is suspected that the power lines in the building (Figure 4) run in metal conduits, are closely bundled and do not necessarily connect directly between all the points measured. It is also unclear how different phases of the three phase supply are distributed. Screening effects and capacitive loading can therefore attenuate the signal. The maximum transfer capability of a power line can therefore only be gauged by testing a free standing uninterrupted length of cable.

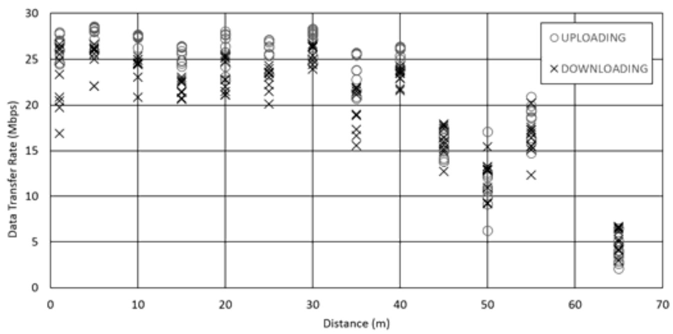

Fig. 7 – Data transfer rates to different positions along a free standing cable – using contacles PLC.

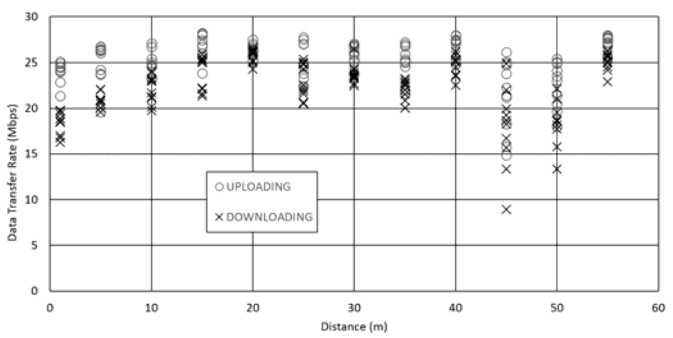

Fig. 8 – Data transfer rates to different positions along a clear line of sight - using direct RF links.

1) *Contactless PLC*

In Figure 7, data transfer rate results are given for 2.45GHz Wi-Fi communication via a contactless PLC set-up (free standing, uninterrupted and non-energized cable). Up to 40m, the results compare well with that of the direct RF link as described in the next section (and Figure 8). After 40m, the transfer rate drops when compared to the direct RF link. A transfer rate around 5Mbps is obtained with 65m of cable.

2) *RF Link*

In Figure 8, measurements of data transfer rate are shown for different positions along a clear line of sight using direct RF links. Up to 40m, data rates are similar to the contactless PLC configuration but are higher after 40m. At 55m the direct RF link does not show a decline in data transfer rates.

IV. CONCLUSION.

In this paper it is shown how a power line can be used to conductively carry and re-radiate 2.45GHz Wi-Fi signals over a distance. Commercial Wi-Fi modems (IEEE 802.11g protocol) were used to transfer data on a power line for up to 65m (non-energised) and up to 20m in a typical industrial energised situation. One modem was coupled to the power line, the line used as a travelling wave antenna and the second modem used in normal RF mode. This was compared to a direct RF link - where both modems were used in RF mode.

The industrial indoor measurements (energized power line) show that the RF link has higher data transfer rates than the contactless PLC. This might be different in situations where there are more severe obstructions and should be further investigated as it is known that Wi-Fi has for example difficulty penetrating multiple stories in large buildings. This should be done as it was shown that in an ideal situation, power line communications at 2.45GHz is not only possible but comparable to direct RF links communications.

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