Performance Comparison of BPL, EtherLoop and SHDSL technology performance on existing pilot cable circuits under the presence of induced voltage

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Abstract. Pilot cable is originally used for utility protection. Then, pilot cable is further utilized for SCADA communication with low frequency PSK modem in the early 1990. However, the quality of pilot cable communication drops recently. Pilot cable starts to deteriorate due to aging and other unknown factors. It is also believed that the presence of induced voltage causes interference to existing modem communication which operates at low frequency channel. Therefore, BPL (Broadband Power Line), EtherLoop and SHDSL (Symmetrical High-speed Digital Subscriber Line) modem technology are proposed as alternative communication solutions for pilot cable communication. The performance of the 3 selected technologies on existing pilot cable circuits under the presence of induced voltage are measured and compared. Total of 11 pilot circuits with different length and level of induced voltage influence are selected for modem testing. The performance of BPL, EtherLoop and SHDSL modem technology are measured by the delay, bandwidth, packet loss and the long term usability SCADA (Supervisory Control and Data Acquisition) application. The testing results are presented and discussed in this paper. The results show that the 3 selected technologies are dependent on distance and independent on the level of induced voltage.

1. Introduction
Pilot cable circuit is a continuous copper wire being used in TNB (Tenaga Nasional Berhad) to provide services such as power system protection and as the communication medium for the low bandwidth SCADA application. Pilot cables were usually laid along with power supply cable between 2 substations. Pilot cable consists of 37 twisted pairs of PE insulated tinned copper wire 0.914mm diameter. The 74 wires are covered by dual insulation with an inner core of cellular polythene and outer skin of solid polythene with hard aluminum wire in between as the wire armor[1].

The pilot cables are subjected to severe induced voltage as it follows the same route as power cable that causes the communication to be intermittent/lost. The easy solutions are to hire lease line service from telecommunication companies or lay fiber optic line to support the SCADA communication. However, these are subject to recurring charges and high cost solutions. There is an immediate need to solve the communication issues of pilot cable for current SCADA applications. Therefore, BPL, EtherLoop and SHDSL modem technologies are proposed to overcome the communication issues. Unlike the existing PSK modem, the 3 selected modem technologies using OFDM to encode the data signal. Theoretically, the 3 selected modems are not susceptible to induced voltage and able to qualify the requirement of...
SCADA communication with 9.6kbps bandwidth and 2s delay. The performance of each chosen modem technology are measured and verified in the field test.

2. Methodology

The selected 3 modem technologies are required to qualified performance requirement of SCADA communication. These requirements include low delay time, acceptable bandwidth and high reliability. Therefore, several testing are required to verify the capability of the modems in establishing SCADA communication on existing pilot cable circuits.

The figure 1 below shows the configuration setup of modem testing:

![Figure 1. Configuration of Modem Testing](image)

Each of the pilot cables are tested based on the configuration in the Figure 1 above. The testing was carried out at both ends of the circuits. Laptops and surge protectors were required to perform the testing at both ends. In order to test delay, bandwidth and packet loss, Ethernet connection is required to connect both laptops to modems. Then, the output of the modem will be connected to a surge protector before connecting to the respecting cores of pilot cables to protect the modem from any voltage spikes.

The 3 tests below will be carried out to determine the performance of pilot cable under difference induced voltage levels and pilot cable lengths (distances):

- Delay Test
- Bandwidth Test
- Reliability Test

Ping application is used for delay and reliability test while Bing application is selected to perform bandwidth test. The ping test is run for around 1 minute with 1 second interval before it is aborted. The average delay of the 1 minute test is calculated for analysis. Bing test is also run continuously for around 1 minute before it is aborted to capture the average bandwidth. For reliability test, Ping application is executed continuously overnight (for around 20 hours) to capture the packet loss. The number of packet loss is recorded and the reliability of the modem technology is calculated.

3. Result

3.1. Delay and Bandwidth Test

The results of delay and bandwidth test of the modems are as the table 1 below:
### Table 1. Delay and Bandwidth Test

| Station | Distance (km) | Induced Voltage (Vac) | Average Bandwidth (Mbps) | Average Delay (ms) |
|---------|---------------|----------------------|--------------------------|--------------------|
|         |               |                      | BPL | EtherLoop | SHDSL | BPL | EtherLoop | SHDSL |
| 1       | 0.4           | 0.28                 | 7.780 | 2.926 | 2.469 | 3.06 | 31.36 | 3.145 |
| 2       | 0.8           | 2.26                 | 7.273 | 0.661 | 2.087 | 2.667 | 50.66 | 3.200 |
| 3       | 2.3           | 4.78                 | 2.027 | 2.564 | 2.255 | 3.333 | 33.00 | 3.474 |
| 4       | 2.9           | 0.80                 | 3.663 | 1.842 | 2.229 | 3.308 | 24.65 | 3.100 |
| 5       | >3.0          | 0.568                | n/a* | 4.714  | 2.197 | n/a* | 56.00 | 3.210 |
| 6       | 3.4           | 9.54                 | n/a* | 4.715  | 2.196 | n/a* | 37.19 | 3.907 |
| 7       | 4.8           | 2.51                 | n/a* | 0.352  | 2.139 | n/a* | 52.67 | 3.454 |
| 8       | 5.7           | 21.18                | n/a* | 0.648  | 2.157 | n/a* | 45.50 | 3.031 |
| 9       | 6.4           | 3.87                 | n/a* | 0.759  | 2.074 | n/a* | 55.28 | 3.174 |
| 10      | 9.3           | 14.41                | n/a* | n/a*   | 2.029 | n/a* | n/a* | 3.350 |
| 11      | >10           | 41.51                | n/a* | n/a*   | n/a* | n/a* | n/a* | n/a* |

*Unable to communicate

Based on the observation in table 1, each of the modem is able to communicate up to certain distance (BPL: 2.9km, EtherLoop: 6.4km and SHDSL: 9.3km). The average delay of EtherLoop modem technology varies from 24ms to 56ms. The average delay obtained for both BPL and SHDSL technology is below 4ms. The delay measured for each technology is within the acceptable range for SCADA communication. The bandwidth of the EtherLoop technology measured has a range from 0.352 Mbps to 4.715 Mbps. BPL modem achieves bandwidth range from 2Mbps to 7.7Mbps. Meanwhile, SHDSL technology has around 2Mbps bandwidth on all of the circuits. The huge bandwidth difference between the substations is believed to be caused by the condition of pilot cable (multiple joints in between). The bandwidths obtained from all pilot cable circuits are qualified for SCADA communication which required only 9.6 kbps. None of the delay or bandwidth test done on the pilot cable circuits with the length >10km because all modems are unable to communicate at this distance range. There is no relationship found between the induced voltage and the delay/bandwidth of the communication for each modem technology.

#### 3.2. Reliability Test

In order the study the reliability of each modem technology, overnight testing were conducted on 10 circuits to investigate the packet loss. However, the reliability of BPL modem is not tested because it is only able to communicate on 4 pilot cable circuits. The result of the overnight testing for EtherLoop modem is shown in the table 2 below:

### Table 2. EtherLoop Reliability Test

| Station | Packet Sent | Packet Loss | % Packet Loss |
|---------|-------------|-------------|---------------|
| 2       | 4452        | 1           | 0.0225        |
| 4       | 4624        | 0           | 0             |
| 7       | 4136        | 0           | 0             |
| 8       | 560         | 0           | 0             |
| 9       | 4060        | 0           | 0             |

The table 2 above shows that EtherLoop modem has no or extremely low packet loss communicating over the 24 hour testing. The highest packet loss observed is 0.22%. On the other hand, the modem technology has 0% packet loss on the remaining pilot cable circuits.
There is no packet loss on the pilot cable circuit which has 21.18 Vac induced voltage. Based
on the result obtained, EtherLoop modem is capable to perform reliable communication
regardless of the induced voltage influence.

The reliability of SHDSL technology is tested on the remaining 5 pilot cable circuits. The
result is as the table 3 below:

| Station | Packet Sent | Packet Loss | % Packet Loss |
|---------|-------------|-------------|---------------|
| 1       | 3676        | 0           | 0             |
| 3       | 4812        | 3           | 0.0623        |
| 5       | 11344       | 0           | 0             |
| 6       | 4256        | 0           | 0             |
| 10      | 4064        | 105         | 2.5836        |

The table 3 above shows that SHDSL modem has no or extremely low packet loss
communicating over the 24 hour testing. The highest packet loss observed is 2.583%. The
second highest packet loss obtained is 0.062% and no packet loss found for the 3 remaining
circuits. There is no packet loss found on pilot cable circuits which has 41.51 Vac induced
voltage. Therefore, SHDSL modem is capable to perform reliable communication regardless
of the induced voltage influence.

4. Conclusion
The objective of this project is to investigate the performance of BPL, EtherLoop and SHDSL
communication on existing pilot cable circuits under the influence of induced voltage. Based
on the results, the proposed technologies are qualified competent to be an alternative solution
for pilot cable communication. The lowest bandwidth measured for BPL (2.027Mbps), EtherLoop
(0.352Mbps) and SHDSL (2.029Mbps) modem technologies qualified for the
9.6kbps SCADA bandwidth requirement. The maximum delay obtain for BPL (3.333ms), EtherLoop
(56ms) and SHDSL (3.907ms) modem technology also fulfilled the 2s SCADA
delay requirement. Besides that, all three of the selected modem technologies are able to
communicate under the presence of induced voltage. However, the performance of each
modem technology is dependent by the length/distance of pilot cable circuits. The distance
limits for each technology are 2900m, 6400m, and 9300m respectively for BPL, EtherLoop
and SHDSL modem technology.

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