

A Position Paper: Cognitive Radio Networking for Multiple Sensor Network Interoperability in Mines

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ABSTRACT

This paper proposes the use of cognitive radio technology for multiple wireless sensor technologies in mines. The work is motivated by the lack of flexible and scalable sensor networks in mines. The proposed architecture uses cognitive radio capabilities to enable several sensor network technologies to be seen as “one” network from the data-analyser’s point of view. The proposed deployment methodology would greatly ease sensor network deployment, maintenance and therefore cost.

1. INTRODUCTION

Mine efficiency and safety are essential to the success of any mine. Efficiency in mines is better understood by how mine ore, tools and miners are tracked and distributed in the mine and mine safety by the gathering and analyzing of sufficient data to make decisions. Mine safety is compromised by the lack of sufficient detail of the environments of work in the mines. Accidents in mines are exacerbated by the lack of relevant and sufficient information in the different mine environments.

Mine parameters that would allow a mine to determine the level of mine safety and/or efficiency may include; pressure, temperature, tremors, noise, light, location, speed, rotation etc. Each of these parameters are required in different mine environments, on different materials and in different circumstances. Sensor networks are normally used, as a wireless communication medium to collect these data. However, one network type cannot collect all the different types of data required to give a holistic picture of the state of the mine. This is because sensor network technologies are application specific. The result is that mines are forced to install independent and disconnected sensor networks, which is both inefficient and expensive.

There are several shortfalls in the current implementations of sensor networks in mines. Shortfalls to be addressed by the proposed architecture are:

1. Lack of inter-operability between different sensor networks
2. Lack of scalability of most sensor technologies
3. The high expenses incurred in deploying new sensor networks
4. Lack of backward compatibility of new sensor networks with old technologies.

To address the above four shortfalls, this study on sensor network connectivity seeks to develop an architecture for interworking different sensor networks in a mine and treating the multiple sensors networks as “one network” over a common backbone. The innovation of this research is in the Interworking of different sensor networks and abstracting them as “one network” using cognitive radio technology.

The need to collect critical, relevant and cohesive data from different mine environments and situations is critical to the understanding of the state of a mine in terms of both safety and efficiency.

Efficient data collection and analysis (data mining) is a critical part of underground mine operations. As such, there is a need to optimize data collection which would in turn allow for efficient data analysis. Current data collection sensor networks are limited in their deployments and use. They are of the same technology type due to compatibility issues, which limits the number of application types that can be run on the sensor networks, and therefore also limiting the number of parameters that can be monitored by the deployed sensor network. The limiting factor to the different parameters that can be monitored is the technology being used on the sensor networks because sensors are application based. The implications are that an independent sensor network to an already existing sensor network has to be deployed to monitor an application that cannot be monitored by another.

The deployment of several independent sensor networks results in inefficient data analysis of collected data. This is because relationships between different data types is lost and data correlations are hard to make. There is a need for a deployment and data collection mechanism that will allow for easy and cost effective sensor network deployment, and efficient data collection for analysis.

We propose that instead of complete and independent sensor network deployment, cognitive radio data sinks be used to interact between different sensor types. Data may then be collected to one central data base for analysis. Interaction between data collection and the sensor networks should also be possible from one central data collection point through the cognitive radio data sinks. The architecture would therefore have a backbone, which can be used by other sensor network types. Costs for new deployments would only be for the actual sensors themselves.

The next section details related works in underground sensor networks, and in Section III we introduce our proposed architecture. Section IV then discusses traffic engineering

issues introduced by the use of multiple sensor networks. We then give a conclusion to our discussion in Section V.

2. IMPLEMENTATIONS AND PROPOSALS OF UNDERGROUND SENSOR NETWORKS

The current generation of underground sensor networks is divided into two categories based on the communication medium; wired and wireless. A significant portion of current underground sensor networks in use is not wireless, and consists of either serial links or standard Ethernet based links between a sensor node and a data sink. This is due to the fact that networks have been used in mines for a prolonged time before wireless sensor networks became more common. A wireless approach to sensor networks is significantly more prevalent in current developments though, due to reasons described in detail in [1].

The implemented wireless approaches to sensor networking are based on the OSI protocol stack, depending on the developer's approach [2]. Due to the challenges of this model when directly applied to underground sensors, different implementations of the standard protocol stack are to be expected [3]. The interoperability of networks developed is therefore not guaranteed, due to incompatibilities of the respective protocol stacks.

The issue of scalability also arises in the current generation of underground sensor networks. Sensors themselves are often limited in their complexity due to the severe energy constraints of the environment. This reduces the features that can be implemented on a sensor, such as additional routing functionality. To mitigate the issues caused by this limitation the implementation of clustered sensor networks are on the rise [4].

Alternative physical layer technologies are currently an active area of research, it is clear underground environments are not ideal for wireless communication using EM waves. High attenuation issues and adverse environments in some mines make signal strength and directionality issues to be addressed. A proposed solution, in [3], to this is to use magnetic induction techniques. This implies that sensors deployed in different parts in a mine could use fundamentally different communication channels and hardware to the routers and data sinks of their respective networks, and that current and future generations of these networks will have compatibility issues with previous generations.

These issues are being addressed in the next generation of wireless underground networks. These commercially available networks are purported to be self-organizing and self correcting, though the software behind these networks are proprietary with the caveat of inter-operability difficulties with other networks [5]. There is a non-proprietary and open architecture specification, called AziSA, under development that aims to make it easier to integrate underground sensors and actuators into monitoring and data networks [6].

No wireless underground sensor network exists wherein different networks from different developers are integrated at the network level. Currently, integration can only be done with data collected at end devices, such as monitoring computers, where correlation between data from different networks is lost.

3. PROPOSED COGNITIVE RADIO ARCHITECTURE

We contrast current sensor network architectures in Figure 1, to our proposed architecture in Figure 2. Notable, is the flexibility that can be realized and ease of deployment in the proposed abstract architecture.

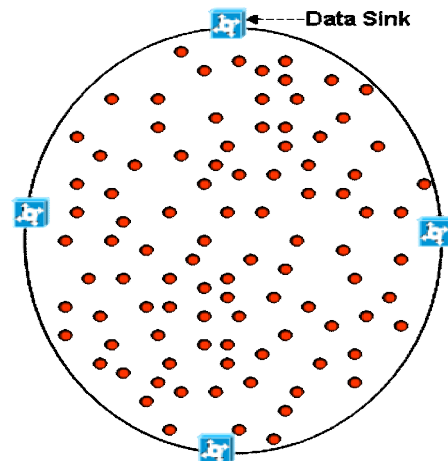


Figure 1: Typical sensor network deployment

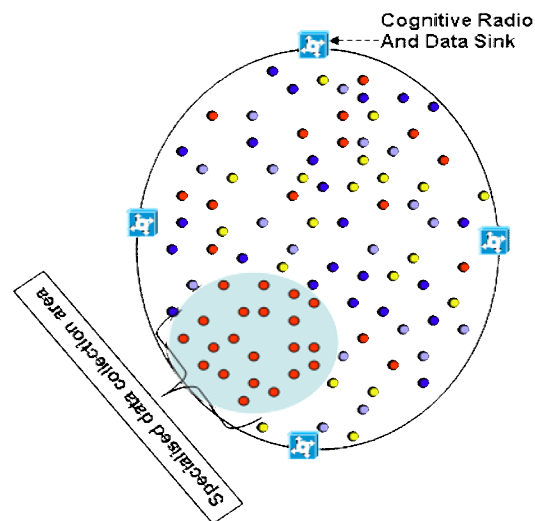


Figure 2: Possible deployment with proposed cognitive radio

Figure 1 shows a typical implementation of sensor networks in mines. Figure 1 shows one type of sensor type distributed in a given area for a sensor network. Most of the current implementations are rigid, not cost effective and therefore do not harness the full potential of sensor networks.

The typical implementation shown in Figure 1 does not cater for monitoring of different applications that require different sensor technologies. Currently a separate sensor network must be deployed and data collected separately. As a result even correlation of data collected in the same area, but with different networks, is lost. Figure 2 shows the proposed ideal

implementation of several sensor networks using different technologies. The data sink, in case of Figure 2, has a cognitive radio that interacts with all the different sensor network technologies in the environment being monitored. The implementation is easier to deploy and correlation of collected data, even in different areas, is possible. Therefore with more relevant and coherent data, critical understanding of the status of mines is possible.

Our proposed cognitive networking methodology in Figure 2 allows for smooth technology migration, as opposed to current implementations in Figure 1, where an existing network would not be able to transition to a new technology. Currently, a complete overhaul has to be done. Various implementations of cognitive radio networking are shown in figures 3, 4 and 5. From Figure 3, the Cognitive Radios (CR) act as gateways to other networks (NWK). NWK 1 and NWK 2 represent sensor networks of different technologies. The networks communicate through the cognitive radio. The cognitive radio can also be used as a gateway with the data control centre. The network administrator can therefore be used to control the performance of any of the networks. The communication between the CR and the data collection centre can either be by wired or wireless communication. More appropriately though, in the context of mines, the communication between the CR and data collection centre would probably be by power communication (Ethernet over Power).

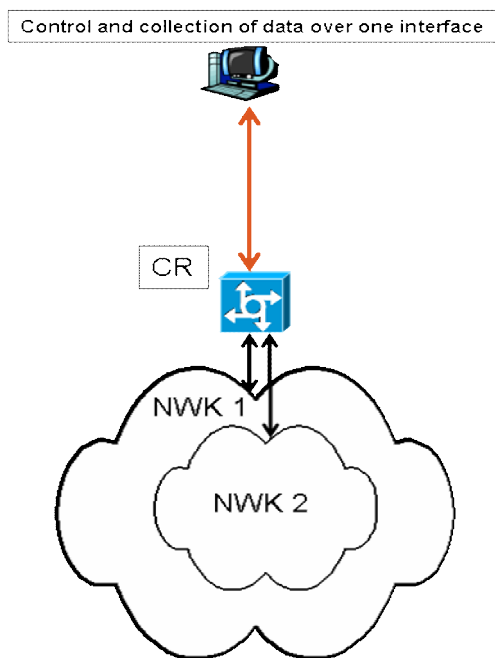


Figure 3 showing implementation of cognitive radio as a gate way between the data collection node and networks.

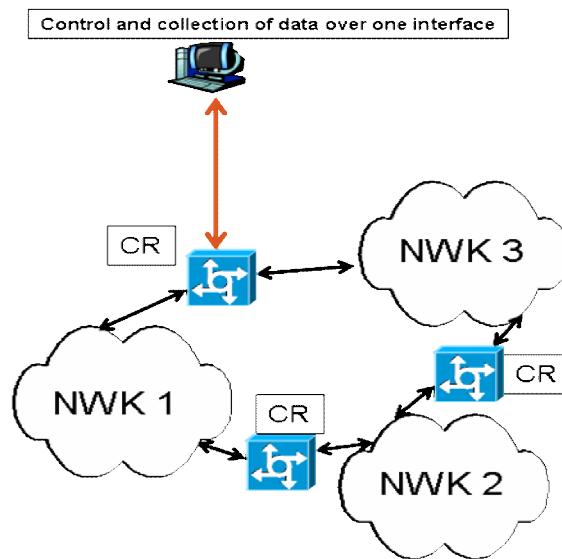


Figure 4 showing interaction between several networks physically separated in one mine

Figure 4 shows an implementation that allows for networks that are not within range of each other to exchange information, and also be controlled or accessed from one central point. The architecture allows for data from different networks to be analysed from one point, making data mining more meaningful. Figure 5 shows a wider implementation using the cognitive radios as gateways. Each of the data collection points can be in different locations, and still have access to all the sensor networks and even to data on other data collection points. The two data collection points can be said to be virtually connected through the sensor networks. This makes it possible to share data and information between networks.

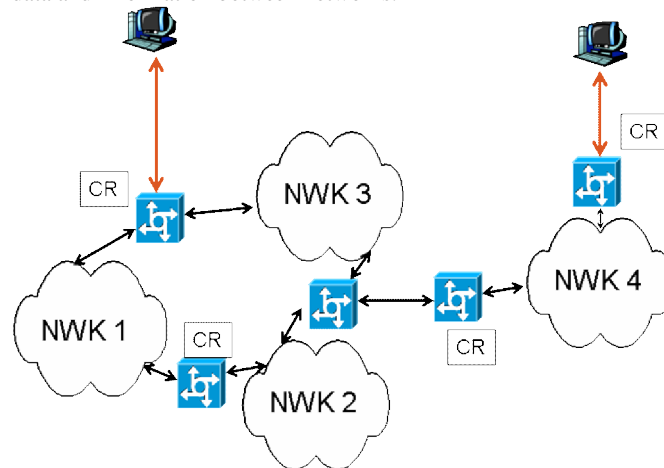


Figure 5 networking and data sharing possibilities amongst different networks in physically separate locations/mines.

4. A CROSS LAYER DESIGN FOR COGNITIVE RADIO

Due to short comings from previous studies, we propose a cross-layered approach to design and implementation of cognitive radio. Below is the proposed cross-layer model. The proposed architecture seeks to not change the OSI layout, but to rather add a module that can be added to the existing OSI layers. In our work we intentionally preserve the modularity of the OSI layered approach, while allowing for cross-layer communication. This is done in to allow for smooth technology transition.

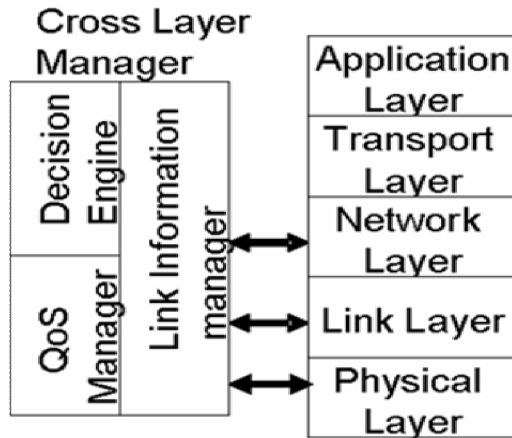


Figure 6: *The proposed Cross Layer model*

Artificial Intelligence is generally accepted as a means to realise a full scale cognitive radio networking. There are several AI methodologies that have been investigated; neural networks, Bayesian networks fuzzy logic and genetic algorithms. Bayesian statistical methods are especially well suited for cognitive radio networks. By definition, Bayesian networks use a prior and a posterior to compute the probability of a given model being right. This is especially the case in Cognitive Radios, where a radio will have to determine the most appropriate spectrum allocation, and then make the best decision. We choose Bayesian Networks to design and simulate a game model for cognitive radio networking.

The term 'secondary users' is used to refer to communication devices that are using bandwidth that is not primarily allocated to them. In a Cognitive Radio Network, secondary channel users would need to know the following aspects of a network, with respect to their needs:

1. What is the QoS supported by a given channel at a given time, transferring certain media?
2. What is the average time, in a given unit time, is available for transmission?
3. Given conditions of available sensor networks, how much data can be accommodated?

In telecommunications research of cognitive radio, there have been two extreme methods proposed for cognitive radio implementation: one proposing a centralized management scheme, while the other proposes a decentralized management scheme. It is less complex to design a centralized management scheme compared to a decentralized one. Decentralized based

proposals assume that the end-user devices will continually scan frequencies, learn from previous behaviour, and determine the most appropriate transmission time and period. While the centralized based proposals assume that the allocation of all transmission times and periods are centrally controlled.

The centralized and decentralized proposals assume a universal control channel. For a decentralized system; when a device decides to transmit in a given time period, it has to alert all other secondary bandwidth users. The centralized system does not consider that the different networks with different technologies are independent of each other. The complexities involved in introducing a universal signalling channel are significant, since not all current communicating technologies do not support such a scenario. The proposals for both centralized and decentralized systems are therefore not "legacy" compatible.

However, both centralized and decentralized methods have advantages that are applicable to a network with cognitive radios, thus the proposed use of an overlay network of cognitive radios over the existing technologies. The Cognitive Radios will see each all the different participating networks as one network. In this approach, the cross-layer manager will be able to deduce the state of each participating network. Information deduced from the Physical, MAC layers, and Network layers would enable routing of secondary traffic through the networks, and even be able to cater for Quality of Service (QoS).

To coordinate the traffic monitoring, admission and control mechanisms and new routing strategies there is a need to use Artificial Intelligence in the XLM and MAC layer.

5. ARCHITECTURE OF THE CROSS LAYER MODULES

The Decision Engine (DE), and Quality of Service Manager (QM) are modeled as agents. Agents are computer programs that have the capability to autonomously take action in an environment in which they are situated in order to achieve design objectives. There are therefore two agents each having a different objective to meet the objective of the Cross Layer Manager (XLM).

The aim of the XLM is to achieve an optimal network performance of the sensor networks the cognitive radio network is in control of. The DE and QM agents' objectives must not conflict with the objectives of the XLM. The aim of the QM is to interpret requests/requirements of the networks into QoS parameters. To achieve this, the QM agent must:

1. Derive network/s optimization parameters at the Physical, MAC, and Network layers.
2. Derive optimal routing schemes for given traffic streams
3. Derive several network performance status and connectivity under different scenarios. These options are then transmitted to the DE, which chooses the most appropriate option.

The aim of the DE is to therefore determine optimal network parameters and behaviors to meet QoS requirements of the QM-agent. To achieve the aim of the QM-agent, the agent must:

1. Use optimization parameters from the QM to derive best network connectivity
2. Determine trade-offs that need to be done in order to achieve best optimization of the network/s.

6. TRAFFIC ENGINEERING ISSUES

Traffic engineering issues need to be addressed in single networks, more so in several networks. The use of cognitive radios as proposed pose several traffic engineering issues. The following are some of the identified issues:

1. New routing algorithms taking into account multiple networks
2. Power consumption resulting from rerouting of traffic
3. Load balancing in the networks
4. Monitoring of packet losses

The functional diagram in Figure 7 shows the handling of the traffic in multiple sensor network types. The cognitive radio controls and monitors the transmission times for each of the networks it is in range of since sensor networks work on the same bandwidth. A network requests to transmit on a channel. If the channel is available and has not been reserved by priority traffic, then the network is allowed to use the channel. Traffic from another network is given priority to traffic from within the network. This is preferred since it would take more resources and more delays if all networks have to notify the source of the traffic to retransmit. Should a network request for a channel and not be granted access, then another channel should be used. The process of deciding on which channel to use in order to meet QoS requirements are done by the DE and QM agents.

7. CONCLUSION

In this position paper, we have proposed an architecture that enables interworking between multiple sensor networks of different technologies. The architecture proposes the use of cognitive radio technologies to achieve this. It is envisioned that the implementation of this architecture in underground mines or applications will greatly reduce costs in addition to improving sensor network scalability and knowledge discovery.

8. REFERENCES

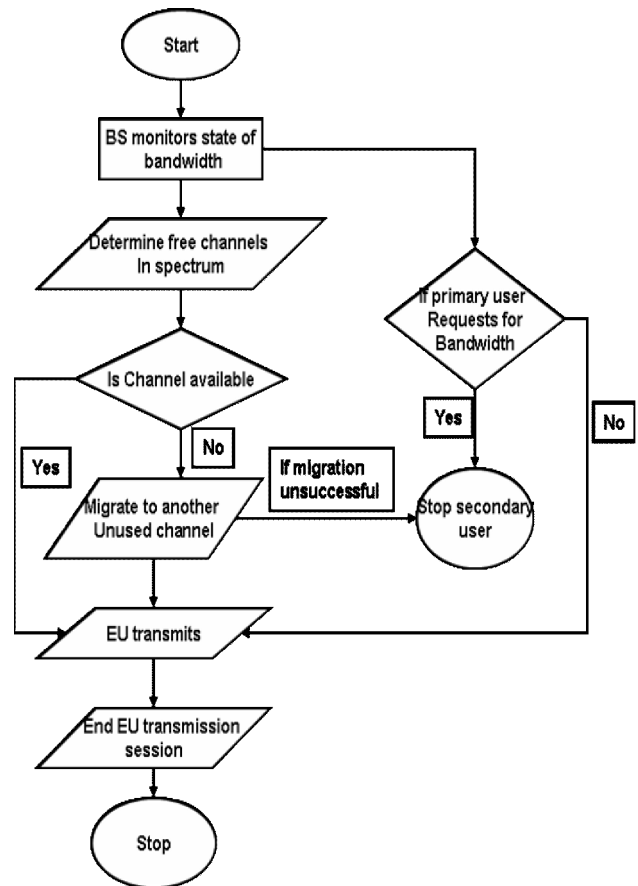


Figure 7: Functional flow chart of traffic handling in cognitively controlled sensor networks