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Proposing a Secure and Reliable System for Critical Pipeline Infrastructure Based on Wireless Sensor Network

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ABSTRACT

A combined approach to enhance the security of oil and water supply pipeline infrastructures is proposed and investigated. The most important factor affecting the performance of the traditional system is the mannual patrolling which is difficult and only provides observation where the patrolling team is present. This study highlighted that by deploying a combination of wireless sensor network in conjunction with the conventional trends and microwave network, the time of reporting any leakage to the control room can be reduced considerably. This in turn provides ability to protect the oil pipelines from further loss or damage and discontinuation of operation. The simulation tests were carried under three different scenarios i.e., minor level leakage, major level leakage and any criminal activity to break a pipeline. Based on the simulation results, it is demonstrated that the reliability of monitoring oil pipelines provided by the new proposed system can be increased. The paper presents the motivation for and the potential advantages of the proposed WSN system for enhancing the security of oil and water supply pipelines.

Key words: Wireless sensor network, security, oil, water, critical pipeline infrastructure, reliability, microwave network

INTRODUCTION

In Saudi Arabia, oil and gas industries heavily depend on more than 152000 km of oil pipelines installed across the country. This network of pipelines connects the shipping ports, refineries and oil/gas wells. Moreover, Saudi Arabia is now considered the world's largest producer of desalinated water supplying drinking water to major urban and industrial areas through a network of water pipelines over more than 4,800 km distance. For example, the capital city of Riyadh with homes more than a million completely depends on the water transferred through huge and long pipelines from Al Shoaiba Desalination Plant in Al-Jubail, Eastern part of Saudi Arabia. Currently, the main concern of Saudi government is to ensure safe and smooth transfer of oil, gas and water to consumers using modern up-to-date technology and tools. But still, there is a possibility of internal damage to pipelines which may be caused due to any terrorist activities, theft or any natural calamities.

Presently, Saudi ARAMCO is the largest company for oil exploring and transporting to the ports. It also manages and controls the pipeline infrastructures by monitoring the pressure, maintaining constant level of pressure at different points and also dividing oil pipelines into different segments. The company still uses the physical patrolling with Ardmco employed teams to monitor its safety. It is believed that a new era of technologies like wireless sensor network can play an important role in improving the process of monitoring such important pipelines.

Sensor network is becoming an increasingly important requirement in a variety of applications such as target detection, surveillance of enemy activities in a battle field, health, chemical use and counter terrorism (Chong and Kumar, 2003; Gutierrez *et al*., 2003; De *et al*., 2002). Some other examples are environment and habitat monitoring, home automation, traffic control, etc. Another possible example is using wireless sensor networks for protecting and monitoring pipeline infrastructure systems especially for oil, gas and water huge pipeline infrastructures (Carrillo *et al*., 2002; Ellul, 1989; Awawdeh *et al*., 2006; Suheil *et al*., 2007).

This study proposes a method to improve the existing oil pipeline security and monitoring system which is cost effective, ensure quality, highly efficient and reliable. This can be achieved by incorporating Wireless Sensor Network (WSN) based system with the existing system. Because WSN sensor nodes are capable to measure a given physical environment in greater detail. A wireless sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific actions. Unlike conventional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks. These unique characteristics make sensor network more beneficial and ease to use over the traditional network.

Many investigators concluded that Wireless Sensor Network (WSN) in the oil and gas industry shed some light on a model of tracking flow-induced vibration to provide means of detection and early warning of integrity loss in pipelines network (Ellul, 1989; Gerasimov and Simon, 2002; Hadim *et al*., 2006; Hadim and Mohamed, 2006; Jawhar and Wu, 2005; Liao *et al*., 2002; Nelakuditi *et al*., 2002; Stoianov *et al*., 2007). Recently, Suheil *et al*. (2007) proposed a model for pipeline monitoring but the technical information is limited only. Changsoo *et al*. (2007) proposed a method for calculating number of sinks and sensors required for pipeline monitoring. Umeadi and Jones (2005) reported some findings of a laboratory based test program to evaluate the potential for vibration sound emission detection in pipelines integrity monitoring. Stoianov *et al*. (2007) presented a system called PIPENET for monitoring large diameter bulk-water transmission pipelines. The above review concluded that in public domain literature limited information are available for WSN based pipelines security, condition and information monitoring.

Akan and Akyildiz (2005) presented an even-to-sink transport protocol for reliable transport in wireless sensor network. However, it should be noted that due to the unique arrangements of the wireless sensors in the case of pipelines monitoring none of the above mentioned models can be adopted for such a case. Based on the above review it may be observed that the topic of continuous real time security and informative reliability of wireless sensor network for pipelines monitoring has not been approached. The proposed system, in this study, focuses on the continuous monitoring security and real time information for the critical pipeline infrastructure.

PROPOSED APPROACH

As stated earlier that the oil transportation across the Kingdom and the rest of the world, is mainly based on the huge critical pipeline infrastructure. These pipelines are mostly laid down in straight and multi curve status (Fig. 1). These critical pipelines are mostly lay down underground with little depth for their protection. The surveillance and security for those pipelines is done through manual patrolling and monitoring.

Manual patrolling is hard, difficult and only provides observations where the patrolling team is present. It is believed that a technique based on joining wireless sensor network with the conventional trends and microwave network together could improve the reliability and quality of monitoring of the oil pipeline infrastructure. The proposed system would detect, identify and localize major anomalies such as theft, terrorism, damage or any disturbance of the pipeline infrastructure at run time. This is achieved because the pipeline infrastructure was divided into different

Fig. 1: Oil refinery with laying pipeline structure

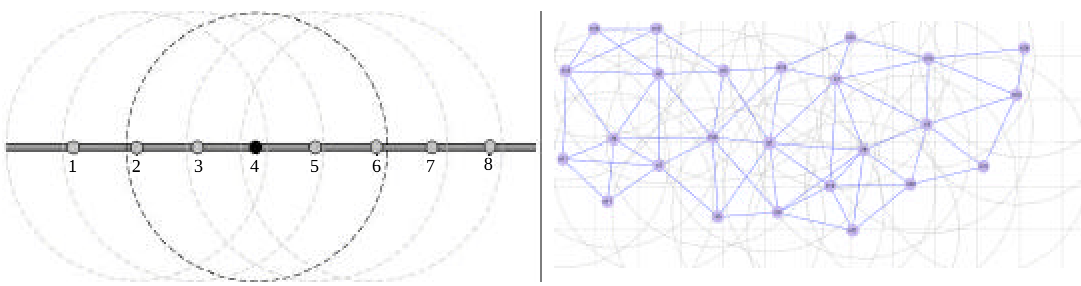

Fig. 2: Working of WSN nodes with a segment of pipeline

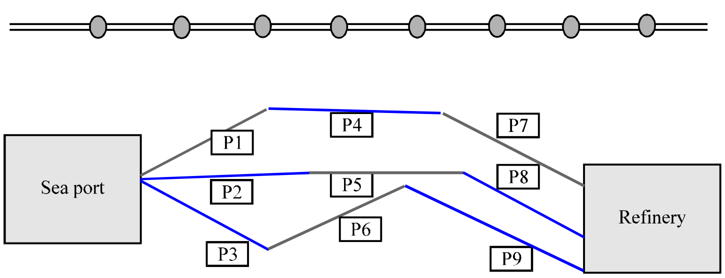

Fig. 3: Simple pipeline structure for oil fields

segments with each having a length of 10 km. The sensor nodes were placed closed to the buried pipes in each segment. Those sensor nodes have coverage area around each node which can be considered all most same in all directions theoretically as shown in Fig. 2. The circle shows the coverage area for each sensor node. Sensors can be closely deployed to the straight and multi direction pipelines as shown in Fig. 3.

The general architecture of the proposed system is shown in Fig. 4. The proposed system consists of sensor nodes, sink nodes, base station and a control room which might be located at head office. Each component of the system perform certain tasks. For example, the wireless sensor

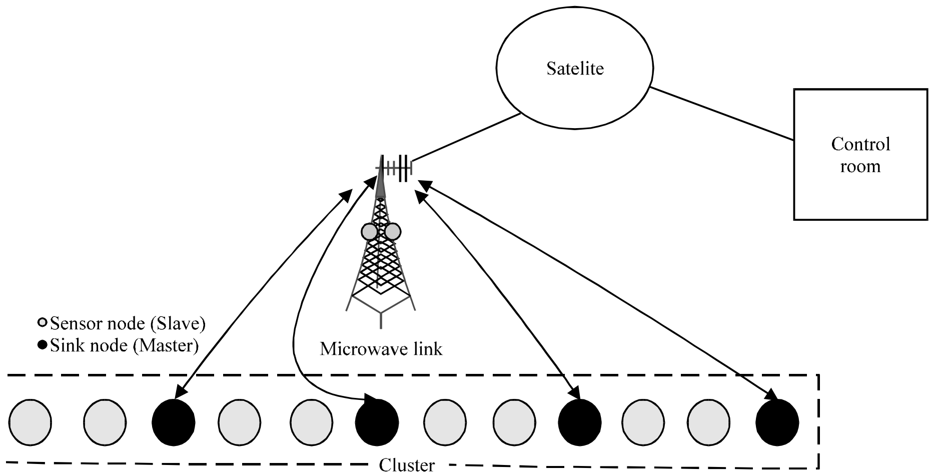

Fig. 4: A proposed system architecture

nodes timely monitor the oil pipelines and report to the sink node if any leakage, breakage or any theft activity occurs. The sink node transfers the collected data to the base station (tower with microwave). Then, base station transfers such data along with its current calculated location to the satellite. A central control room receives all such data from the satellite. The proposed system covers all these processes in few seconds with its exact information of the problem site. Therefore, it is believed that this mechanism would boost the security at the run time and improve the efficiency and reliability of the proposed oil transferring system.

SIMULATIONS

The proposed system was tested through different simulation tests and their results were compared to the conventional available security system. Network Simulator 2 (NS-2) is used for simulation purpose. Such simulator provides a graphical interface called Network Animator (NAM). This graphical interface helps to generate trace files in order to control the simulations during run time. An example of the animated tool NAM is shown in Fig. 5.

Different parameters were considered during the simulation process. Some of those parameters are shown in Table 1.

RESULTS

As stated earlier that oil pipelines are mostly lay down underground at shallow depth for their protection. Therefore the process of noting the leakage at limited time seems to be difficult when using the existing system. This is because security of pipeline infrastructures in such system normally checked and monitored with patrolling and pressure measuring system from one to another end. An important requirement for the effective operation of the proposed system is the capability for this system to minimize the time of reporting any leakage to the control room. This in turn can provide ability to protect the oil pipelines from further loss or damage and discontinuation of operation. Various simulations tests were applied to check the security, reliability and real time monitoring for the proposed system and then compared it with the existing system approaches. These simulation tests were conducted under three different assumptions. Each assumption is evaluated based on 11 different events. These events present different locations. The

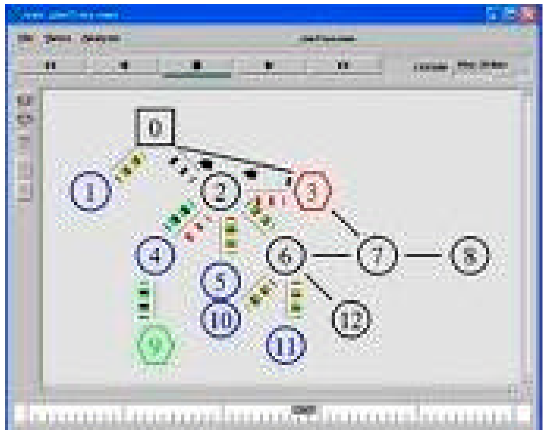

Fig. 5: NS-2 NAM graphic animator tool

Table 1: Simulation parameters

Parameter	Values
Network area	200*200 m or 400*400 m
Number of sensor	100 or 400
Location of sink	Uniform random
Radio range	Center of area
MAC layer	IEEE 802.11
Unusual event sources	4
Routine data sources probability	p
Failure rate	f
Time-out constant ξ	1/r
Delay for retransmission M	0.02 s
Data rate of unusual events	λ_U
Data rate of routine data	λ_R

following subsections “minor level of leakage” to “criminal activity to break a pipeline” introduce those assumptions as well as present the experimental investigations and an analysis of the results. The results are discussed based on three different parameters. These are Event occurrence Data Time (EDT), Access Time of Existing System (ATES) and Access Time of Proposed System (ATPS).

Minor level leakage: In this assumption, different simulation testes were applied to track the minor level leakage in the pipeline and then reported to the control room. This includes the security, reliability and monitoring access time for both systems. Figure 6 clearly shows the vast difference in reporting or access time between the conventional and the proposed system.

It can be observed from Fig. 6 that the conventional system reported the event in about 330 sec after its occurrence time. On the other hand, the proposed system can reduce the access time to only 15 sec after event occurrence. The reduction in access time achieved with such system is more than 10 times efficient as compared to the conventional system. These results are in agreement with the earlier suggestions that the use of conventional system require more time to monitor this type of leakage. The possible reason is that this system can only monitor the leakage

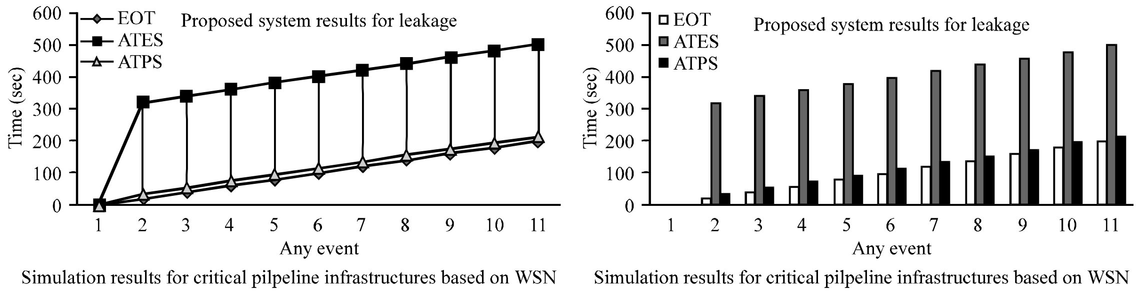

Fig. 6: Performance of proposed and conventional systems based on minor leakage monitoring in oil pipelines

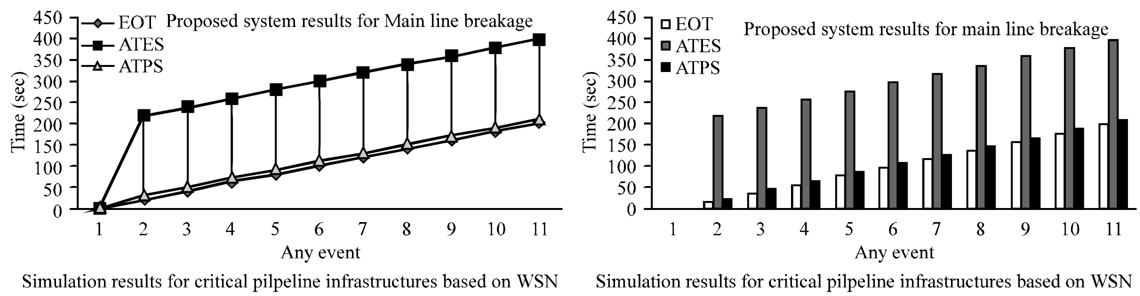

Fig. 7: Performance of proposed and conventional systems based on major leakage monitoring in oil pipelines

loss through its pressure observation techniques for different pipeline segments. It even required more delay in case of nights patrolling, while the proposed system can work with same quality and efficiency all the time.

Major level leakage: In this assumption, simulations were applied to monitor the major level leakage. This level of leakage may be caused by major damage or pipeline breakage due to pressure. It can be seen in Fig. 7 that the conventional system leads to an access time which is slightly better than the one offered by the same system in the previous section. The reason for such behaviour is that the conventional system could report this level of leakage quickly due to the drop-down of the pressure which can be noticed at different control segments. Therefore, this level of leakage can easily be monitored during night timings, as it becomes a sudden cause of drop in pressure and can easily be monitored through pressure gauges. However, the performance of such system, in terms of access time, is still well below that of the proposed system. The use of proposed system is seen to reduce the access time by about 7%. This in turn can save major resources and enhance their safety and security.

Criminal activity to break a pipeline: In this assumption, simulations were applied to monitor the status of oil pipelines and prevent any sabotage operation. It is observed from Fig. 8 that the lowest access time is obtained when monitoring of the pipelines is based on the use of the proposed system. The access time, obtained by the proposed system, is 5 times faster than the one obtained by conventional system. In such scenario, the proposed system can provide a report even before the

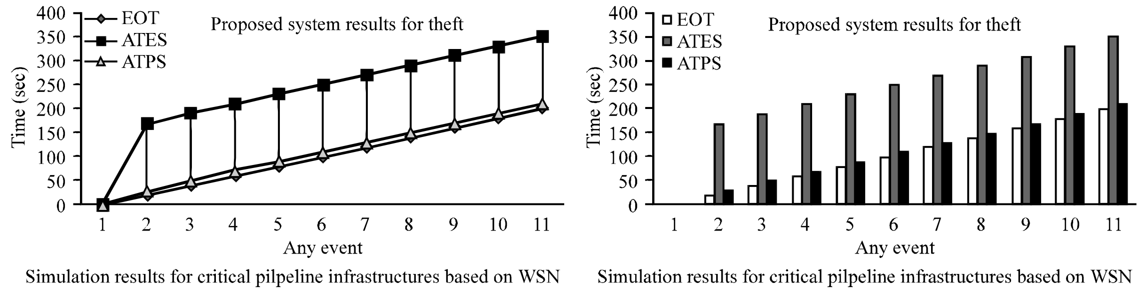

Fig. 8: Effectiveness of proposed system in monitoring the critical oil pipelines from criminal activities

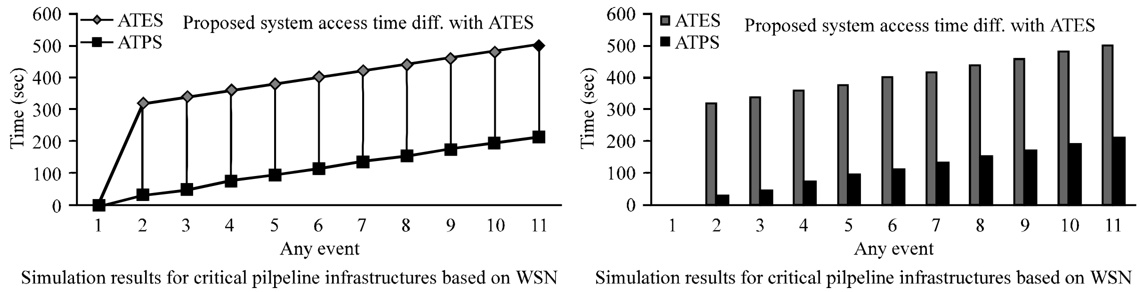

Fig. 9: Overall performance of the proposed and existing monitoring oil systems

sabotage activity occurred. This is, as explained earlier, because sensor nodes will be deployed across the pipelines to monitor any unwanted event occurrence. On the other hand, conventional system can only report an event when it occurred since it is based on patrolling and pressure measuring system from one to another end.

A performance assessment of the overall results in terms of access time is presented in Fig. 9.

It was observed from Fig. 9 that using the proposed system in monitoring oil pipelines appears to provide better performance in terms of reducing the access time. These outcomes confirm the earlier suggestion that the reliability of monitoring oil pipelines can be further increased if a mechanism of joined wireless sensor network with the conventional trends and microwave network is applied.

Another major benefit offered by such combined system is the capability to monitor the critical pipeline infrastructure at run time under any hard circumstances which is a leading edge over the conventional security system. The findings of the study agree with many researchers. For example: Cinque *et al*. (2006) addressed the current limitations and posed the reliability requirements for dynamic structure monitoring using wireless sensor network. Abo El-Fotoh *et al*. (2006) approached the problem of modeling and evaluate the coverage oriented probability of WSN subject to common cause failure. Xing and Michel (2006) defined a WSN reliability measure considering the aggregate flow of sensor data into a sink node. Chiang *et al*. (2004) dealt with the problem of reliability and security modeling in an integrated manner. Cai *et al*. (2006) proposed and evaluated scalable architecture of WSN nodes for increased availability. Shrestha *et al*. (2007) shed some light on the problem of reliability modeling for large scale wireless sensor network.

CONCLUSIONS

A study of the use of wireless sensor network in conjunction with the conventional trends and microwave network, in monitoring oil pipelines, is presented. Simulation tests were carried under three different scenarios to check the security, reliability and real time monitoring for the proposed system and then compare it with existing system approaches. For all scenarios, the results showed that the use of the proposed method leads to better performance, in terms of access time, than the conventional system. This in turn increases the reliability of monitoring oil pipelines and provides ability to protect the oil pipelines from further loss or damage and discontinuation of operation. Additionally, it has been shown that the proposed system is capable to monitor the critical pipeline infrastructure at run time under any hard circumstances.

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