Abstract — TESS research project solves communication and energy issues for remote machines in nuclear environment. The energy and communication signal are transported by an optical cable from the control post to a relay on the working zone. Working robots are remotely controlled by the relay, which broadcasts wireless transmission. Working robots can recharge their batteries by plugging on the relay, without leaving the working zone. The proof of concept of the telecom architecture has been done. The relay is not realized.

Keywords—nuclear intervention, remote machine, robot, telecommunication, energy, optic, WDM, wireless, LTE

I. INTRODUCTION

Kerntechnische Hilfsdienst GmbH (KHG) was founded in 1977 by German companies operating nuclear power plants, the fuel cycle industry and major research centres. Its objective is to stabilize a power plant following an accident or breakdown, analyse the cause and eliminate the resultant effects. Its operating architecture is based on three kinds of machines [1]: - the Control Post, supporting the robots drivers, linked by radio to MTS1 an antenna mounted on a truck 10km apart - the automatized relay called MTS4, connecting the working robots and the antenna in a 0.5km radius - the working robots like MF4, MF6 and LMF [2]. In 1988, after the Chernobyl accident, the Group of Robotics INTervention on Accidents (INTRA) has been created by EDF, CEA and Areva and has conceived its own fleet of robotics machines. In case of outside intervention, its operating architecture is based on the Mobile Control Post (MCP) supporting the robots drivers, which is linked by optical fiber to a 5km distant automatized relay called Erelt. By radio transmission emitted by the Erelt, the Erase robot is remotely controlled. The energy life is respectively equal to 100h, 80h and 10h for the MCP, the Erelt and the Erase [3]. In case of inside intervention, the energy life is smaller for Eros robot (Engin Robotisé d’Observation et de Surveillance i.e. Robotised Device for Observation and Surveillance) [4] equal to 7h. Both architectures of Intra and KHG are based on a control post, a relay and remote machines and present three main drawbacks: a limited distance, a small energy life of remote machines and impossibility to use several remote machines at once. Recently, remote machines have been developed for nuclear environment, like Meister [5], the four-legged robot [6], Arounder [7], Astaco-Sora [8], Quince [9], Packbot [10] [11] [12] and many others [13] [14]. Controlled by an operator, they perform complex operations (heavy lifting tasks, decontaminating, measurements, opening and closing of valves). New ideas have been also published for improving the interface between the operator and the remote machine [15] [16]. Even so, the problem of the energy and communication remains:

- If an umbilical cable is used, no battery must be reloaded or changed. However, the mobility of every working robot is limited due to its cable length and the presence of the cables of the other robots. Few working robots can work in a same time.

- If a wireless transmission is applied, the mobility of remote machines is increased. However, there is a risk to lose the signal for inside intervention and the remote machines operability is strongly reduced by the small energy life of batteries.

TESS research project aims to propose a solution based on a telecom network for remote controlling several machines and in the same time increasing the energy life of remote machines and the working distance. The proof of concept of the telecom architecture has been done. The relay is not realized.

II. TESS RESEARCH PROJECT — THE BASIC IDEA

The Telecommunication and Energy Supplying System (TESS) respects the architecture designed by INTRA and KHG, based on a control post, a relay and remote machines. The communication and energy line is not constituted by the remote machines themselves [17], but realized by a dedicated system. In the control post and the relay, wavelength-division multiplexing (WDM) equipment manages optical downstream and upstream data flows [18]. In the control post, the network management system controls the wireless telecom cell in which remote machines move and work. The generating unit located near the control post supplies the relay with energy. The control post and the relay are interconnected by the telecom cable transporting all necessary data via optical fibers and the energy via a conductive layer. In the relay, the antenna broadcasts the LTE telecom cell in order to control remote machines. Radiation shielding protects the electronic of optic...
and wireless devices against gamma emission. Finally, an electrical plug is mounted on the relay which allows remote machines to recharge their batteries without leaving the working zone: their operability is improved (Fig. 1). Because remote machines are driven by wireless transmission, they are not bothered by umbilical cables. TESS can be constituted of one or several relays. Its several relays optimize the space occupation and generate small wireless cells. A relay is linked to another relay by the cable. Every TESS relay is used as a server for controlling working remote machines. By using WDM and LTE technologies, many more working robots could be used for collaborative robotic tasks.

### III. TESS RESEARCH PROJECT - TECHNICAL DESCRIPTION

#### A. The relay – Research project to be realized

The telecom cable connects the control post and the several relays (Fig. 2). The optical signal is detected and the high voltage energy is recovered. The high voltage is transformed in low voltage for supplying all the “i” relay’s elements, i.e. the relay’s driver, optical sub elements, wireless sub elements. The low voltage is transformed in high voltage for the next “i+1” relay. The electric plug feeds the working remote machines joined to the “i” relay. This plug can be linked to the high voltage for heavy working machines which need a lot of energy or linked to the low voltage for light working machines which need little energy.

![Fig. 1. The basic idea](image)

#### B. The optical/wireless transmission – Proof of concept

In order to transport signal over 50km without repeater, a WDM optical network is inserted between the wireless LTE units, composed of the Remote Radio Head (RRH) localized in the relay and the Baseband Unit (BBU) localized in the control post. The BBU and the RRH constituted the evolved Universal Terrestrial Radio Access Network (eUTRAN). These links are based on Black and White (B&W) optical transmission and use Common Protocol Radio Interface (CPRI). The global TESS configuration presented in the fig. 3 is the simplest topology. The control cell cabinet is composed of a WDM 10Gb/s 1830PSS32 [20] and one BBU unit. The telecom relay is composed of one WDM 10Gb/s 1830PSS4 [20] and three 2.5Gb/s RRH. The WDM transport is based on the interconnection point to point type between the 1830PSS32 and the 1830PSS4. Black and white transport is used for the link between the 1830PSS32 and the BBU and also for the link between the 1830PSS4 and the RRH. The signal is transmitted from the RRH to the remote machines using wireless technology. From a network point of view, the robotics elements are similar to mobile phones in a classical wireless network, called User Equipment (UE). Based on these considerations, we symbolized in all the schemes bellow the robotic elements by “UE”.

![Fig. 2. The relay](image)

The WDM optical signal is detected at the telecom cell reception point. Every relay has its own wavelength. By this way, the transmitted data size is greatly increased. For the “i” relay, the downstream and upstream wavelengths are respectively $\lambda_i$ and $\lambda^‘i$. An optical add and drop multiplexer (OADM) drops the downstream optical signal joined to the relay “i”. The other wavelengths pass through and go to the next “i+1” relay. The optical signal brought by $\lambda_i$ is detected. A part of the signal is used for driving the relay, the other part is used for driving working remote machines joined to the LTE broadcasted telecom cell. The upstream signal coming back from this remote machines is coded and brought by the wavelength joined to this relay $\lambda^‘i$. The optical signal is added to the upstream optical signal coming from the other relays by the OADM and goes to the control post. Finally, the electronic and optoelectronic devices must be protected against gamma rays [19], by using lead or tungsten shields. The density of these metals imposes to compact Telecom equipment to limit the weight of the shields and makes lighter the relay. For example, a box adapted to the OADM 1830PSS4 [20] with 5cm thickness, for an approximately 10000 Gray maximum integrated radioactive dose has a weight around 300kg.
dedicated special software package for the 1830PSS4 equipped with 4DPA2 card.

Fig. 4. The different transponder and optical cards of the proof of concept

C. LTE advantages for driving robots

The LTE specification [22] defines a downstream rate of at least 100Mbps and upstream rate of at least 50Mbps for UE category 3. These high rates are necessary for transmitting orders from the control post to the robot and essential for receiving videos from cameras mounted on the robot and by this way for understanding the robot neighbourhood. LTE offers also RAN (Radio Access Network) round-trip times of less than 10ms [23]. This small latency is very interesting for remote machines drivers for feeling the move of the machine.

D. The evolved Packet Core for driving robots

The Evolved UTRAN (eUTRAN) evolution is accompanied by an improvement of the non-radio aspects, which includes the Evolved Packet Core (EPC) network. EPC has logical nodes and functions [24]:

- Mobility Management Entity (MME) authenticates and localises the robot.
- Serving Gateway (SGW) provides the robot with an IP address and maintains the data path between the eUTRAN of the relay and the PGW.
- Packet Data Network Gateway (PGW) is the interconnection between the EPC and the external IP networks (PDN) i.e. the robot driver and routes data packets between the robot driver and the robot.

E. The telecom cable

The cable transports data and energy. It is composed of optical fibers at the center of a vault made of iron cables and a copper conductive layer. The Alcatel Lucent Submarine Networks’ product is designed for delivering 1A electrical intensity under 10kV voltage, i.e. 10kW. It is relevant to know how many machines can be powered by 10kW. For example, Citroën has developed the C-Zero, its new electric concept car. The power of its engine is 47kW, with a recharging time of 6h for a 16A 220V mono-phase current or 30min for a 32A 400V three phase current. So 10kW powers three C-zero in a same time, 3.5kW per car with a recharging time of 6h. The current cable is power enough for a small number of remote machines or more machines consuming little energy.

F. The global Telecom sketch - Research project to be realized

TESS main elements are: 1830PSS optics network elements, wireless network elements like the eUTRAN constituted by RRH and BBU, 5620 SAM (Service Aware Manager) for controlling all telecom optic and wireless elements [25], alimentation infrastructure and specific cable. The fig. 5 summarizes this global TESS architecture.

Fig. 5. The global Telecom sketch

IV. TESS research project - Use case

TESS research project serves in different fields such as maintenance, decommissioning or accident interventions. It makes new operations of collective robotic systems possible. TESS is declined under two approaches: a fixed one adapted to distant intervention, and a mobile one for operations requiring flexibility and mobility. It is interesting to merge the two models to obtain a global scalable system. Fixed TESS approach is adapted to the bunker as defined by the safety assessments of French Nuclear Safety Authority (ASN - Autorité de Sécurité Nucléaire) [26] and improves them. The bunker solution is composed of a fixed control post and several relays (Fig. 6). They are interconnected by the submarine cable constituted of optical fibbers at the cable centre and a conductive layer around. Once installed, this cable will not be removed anymore. Its length is from 10km to 50km, and the optical signal does not need to be amplified. Remote machines or power plants are controlled by rescue team protected inside the bunker far from the power plants.

Fig. 6. The fixed TESS

In the mobile TESS, the control post and the relay or several relays are mobile (Fig. 7). The several relays mobile TESS could have a moving similar to a snake [27], when the cable between two relays is rolled. It spreads its relays as it progresses for making a communication and energy line (Fig.
The mobile approach is adapted to maintenance, accident intervention and decommissioning inside a building, where electromagnetic shields stop the wireless transmissions.

![The mobile TESS](image1)

**Fig. 7.** The mobile TESS

It is possible to assemble fixed TESS & mobile TESS to form only one system. In this way, the rescue team can drive the remote machines from the bunker far from 10 to 50km via the fixed relay and the mobile one (Fig. 9), and to operate inside several nuclear reactor simultaneously.

![The mobile TESS](image2)

**Fig. 8.** The mobile TESS

**CONCLUSION**

In this paper, we demonstrated a telecom architecture based on optic and wireless transmissions for working robots in nuclear environment via TESS project. The energy issue can be solved by using a telecom cable with conductive layers. TESS project objective is to improve the low independence of robots or remoted machines concerning the communication and the energy for increasing their use. Because TESS makes possible new collective robotic operations, it can serve in different fields such as maintenance, decommissioning or accident interventions in nuclear environment. TESS is also relevant for other applications like chemical industry, deep mining or submarine intervention.

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**REFERENCES**