

Hybrid Wireless Networks combining WLAN, FSO and Satellite Technology for Disaster Recovery

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Abstract—This paper presents a combination of Free Space Optic systems with WLAN and Satellite Communications to provide Video conferencing and data transfer for use in Civil Military Cooperation and disaster recovery applications. A modular communication system developed at TU Graz is described, which facilitates worldwide access to the Internet or any other network (depending on the particular application) by combining Satellite Communications, FSO and WLAN networks. Satellite communications provide the necessary backbone for communication between distant locations in the world, Free Space Optics allows quick installation of broadband fixed wireless links without the need of any cables and finally, the WLAN offers connectivity to mobile users in the network cell, located at the target destination.

The second part of the paper presents results of a system demonstration at a civil-military exercise in Spring 2004 in Austria, where mobile Satellite Earth Stations were used in combination with FSO and WLAN to enable Videoconferencing between military and civil organizations.

Index Terms—Disaster Recovery and Management, Hybrid Wireless, Free Space Optics, Satellite Communications, WLAN

I. INTRODUCTION

Applications for disaster recovery require broadband access from the disaster area to the rest of the world. In the case of destroyed terrestrial infrastructure, connections based on geostationary satellite technology (GEO) offer quick access to any location on earth. For practical reasons it is convenient to set up all applications on the Internet Protocol (IP) and to use standard networking technologies, like Ethernet for data transmission. This is the most flexible approach which allows to have several applications running in parallel on standard software, using the same network connection. Another important aspect is the flexibility of the physical connection to the location of the application and the time which is needed for system installation. Considering these aspects, we have developed a transportable ground station including Free Space Optical (FSO) connections to the actual disaster location, as well as an optional Wireless Local Area Network (WLAN) distribution to mobile users. Slightly adjusted TCP/IP is implemented over the whole link and standardized Ethernet connectivity is offered in order to use of-the-shelf user equipment. The paper is structured as follows: After describing each technology in some detail, the concept of the system combining all technologies is proposed and the realization and demonstration described.

Finally the use of the hybrid system for civil-military cooperation and disaster management is presented. In a CIMIC exercise example a mobile satellite earth station (equipped with FSO and WLAN) was used for Videoconferencing between different organisations.

II. HYBRID WIRELESS COMMUNICATION TECHNOLOGIES

Different wireless communication technologies exist, each of them with specific advantages and disadvantages. By putting together a system combining those technologies by exploiting the specific advantage, very flexible systems can be implemented. However considerations regarding which protocols to use and the adaptation to the specific characteristics of the physical transmission have to be taken into account. Hence, the characteristics of the three used technologies are described.

A. Satellite Communications

The main advantage of satellites in the geostationary orbit 35 785 km above the Earth equator is that seen from the Earth, they seem to remain at a fixed location, because their rotation movement is exactly equal to the Earth's surface. This allows to mount ground station antennas at fixed positions always pointing to the selected Satellite. GEO satellites can offer access to users in large geographical regions depending on the provided coverage area. In principal 3 GEO satellites can cover most of the Earth's surface. Negative aspects are the high free-space losses due to the large distance requiring high antenna gain for compensation and the delay time which is in the order of 240 ms for an earth-satellite-earth link (480 ms round-trip time). Alternative concepts with many Low Earth Orbit (LEO) satellites avoid large directional antennas and reduce delay, but these systems are complex and could not show commercial success up to now. GEO connections are state of the art and our choice of technology.

The so called "bent pipe" satellite concept uses transparent transponders, which relay the received signal after amplification back to the earth again.

This concept allows different applications over the same channel and leaves freedom for new implementations in the ground station. It also minimizes additional delay time. Customers can rent bandwidth in fractions of a transponder size for time periods as needed. More efficient concepts also offer bandwidth on demand.



Figure 1. Mobile Satellite Earth Station connected with FSO

B. Terrestrial Free Space Optics

In contrast to long-range Satellite Communications, FSO is a technology which can offer cost-efficiently very high data rates over short distances in the order of up to 1 km. Digital data is transmitted in the base band over an intensity-modulated beam of infrared light and converted by optoelectronic components which are well known from fiber optic technology. Optical carrier frequencies in the order of 200 THz (1550 nm) or 350 THz (850 nm) are free of any license requirements worldwide and cannot interfere with Satellite or other RF equipment.

Fog is the most important cause for attenuation in the optical wave link. For a stand-alone Free Space Optics system, fog can cause attenuation of up to 100 dB/km in the climate around Graz [1], while rain can cause attenuation up to 25 dB/km in a thunderstorm at a rain rate of 150 mm/h. To achieve high availability, as required by many communication applications, a high link margin is necessary, limiting Free Space Optics applications to less than 0.7 km distance. A margin of 20 dB/km for a FSO system would allow operation under practically all weather conditions and seems to be feasible for up to 3 km link distance. Availability measurements over a 2.7 km link distance with a margin of 7 dB/km for the Free Space Optics system show the expected behaviour of a reduced reliability [1]. To ease rapid installation, FSO systems operating in the near infrared range can also be used for connections through glass [5].

The exclusive use of a large bandwidth (due to the spatial limitation of the light beam) and the good characteristics of the free-space optic channel allow to transmit any 2-state digital modulation format in the baseband under the same protocol as specified for fiber cables. In RF technology where bandwidth is precious, this would be considered as not very efficient. But especially for Ethernet networking applications this means that the same physical layer data format specified for fiber optic transmission can be used and over moderate distances the channel has similar low bit error rate characteristics even without any forward error correction (FEC) implemented.

Hence, this concept is advantageous regarding delay, because every code or standard conversion always diminishes the application data rate and produces additional delay. Especially in combination with the GEO satellite channel in real-time applications, this is a key aspect which simplifies the concept. The weak point of FSO is an increased weather influence

which limits availability for longer distance applications. For distances in the order of a few hundred meters however the weather influence can be fully compensated by a high specific power margin in the order of 70 dB/km.

C. Wireless Local Area Network

WLAN systems according to the IEEE 802.11 standards family offer wireless shared connectivity of up to 54 Mb/s overall data rate in the 2.4 and the 5.6 GHz radio frequency bands. Using omni-directional antennas, several users located in a room or a building can share the network capacity of a so called access point. This is different to FSO systems, where the full data rate is dedicated to one directed connection. Moreover, there is also a change in the protocol and coding standard from Ethernet 802.3 to WLAN 802.11. This change is necessary to adopt data transmission to the characteristics of the RF physical channel, to handle echoes, signal delay time and multipath distortion and to some extent also interference with other RF systems using the same free frequency band. Depending on distance and noise floor, the data rate switches from 1 Mb/s up to 54 Mb/s overall rate. As available communication resources in WLAN networks are shared by all users, mechanism for dealing with / avoiding collisions have to be implemented. This means in practice that the actual total data throughput will be in the order of 30 – 40 % less than the maximum. However, the main advantage and the reason for the success of WLANs is the possibility to set up a network cell with several mobile users sharing a broadband connection and to allow even non line-of-sight connections through walls over short distances.

III. SYSTEM SETUP

PCs for disaster applications are usually located in buildings or temporary shelters without network infrastructure. Local PCs running specific applications need access to remote computers providing application specific information (e.g. X-ray images for Telemedicine).

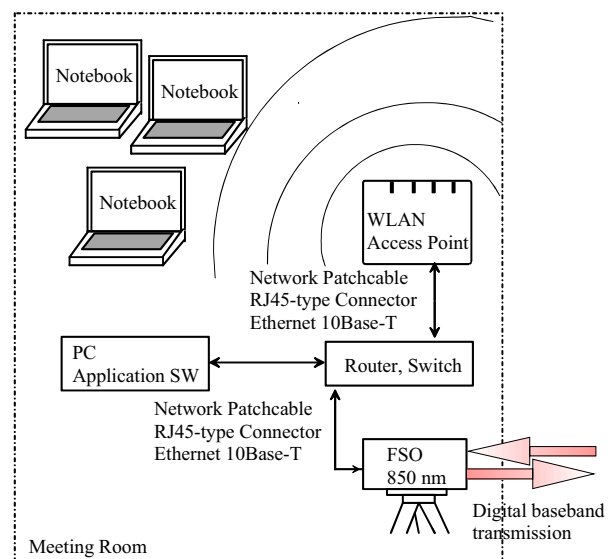


Figure 2. Mobile Access in the WLAN network cell for applications in the meeting room

The connection to remote PCs is established via the hybrid WLAN/FSO/Satellite link. The data to be transmitted is transformed into a IP data stream and Ethernet packets for the transport over the WLAN. A WLAN access point is interconnected by a network switch or a hub with the FSO system. The data stream is transmitted over the FSO link to the outdoor Satellite ground station equipment.

The complete satellite ground station and a FSO unit are located outside the building to enable free line of sight for the antenna to the satellite. The Ethernet network data stream from the FSO system is connected to the Satellite modem over a network cable with RJ45 interface.

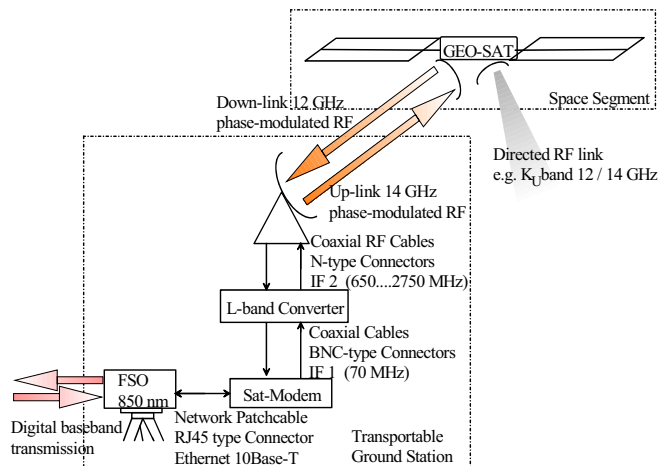


Figure 3. Outdoor components and physical interconnections

The system parameters of the ground station (antenna size, transmission power, coding rate..) depend on the available satellite capacity and required data rates are calculated with a link budget.

In addition to the considerations for the physical channel, there are also adjustments in the TCP protocol necessary to enable efficient data packet transmission over the Satellite link. Due to the high delay in the GEO Satellite channel the acknowledgements of correctly received packets arrive much later than usual. To avoid a break in packet flow, it is necessary to increase the allowable number of packets which can be sent before an acknowledgement is required. Therefore the TCP parameter "window size" has to be adjusted in accordance with the bandwidth delay product of the link. Additionally, options for selective acknowledgement and fast retransmit should be activated, if not already in operation in the used TCP implementation. An increase of the initial window size to 4 (1 per default) after slow start has proven to increase TCP throughput in Satellite links remarkably [2].

For the fixed wireless connection of the ground station equipment to the location where data access is needed a FSO system (figure 8b) developed by OptiKom (the group for Optical Communications at TUG) is used. It features a waterproof RJ45 connector for direct connection to standard Ethernet networks and uses the same modulation concept through free air as specified for fiber optic Ethernet connections. For convenience this transmission system has implemented power-over-Ethernet, so one cable plug for each unit is enough to establish the physical link. To simplify the

installation procedure, the system is mounted on tripods. The adjustment procedure is very easy, only pointing over the housing to the opposite system is required for verifying the link with the built-in indicator. For typical distances of 50 to 250 m between satellite ground station and the indoor network any weather impact can be compensated and the wireless connection behaves like a wired cable connection for any data packet size. To prove this, the OptiKom FSO system was evaluated with an Ethernet network tester over 450 m distance during daytime in summer in comparison with the theoretical Ethernet limit and the measurement of a cable connection [5]. The hybrid network setup is shown in figure 4, where it has been demonstrated for a Telemedicine application between a hospital in Graz and Vienna at the UNO-City Center in June 2003.

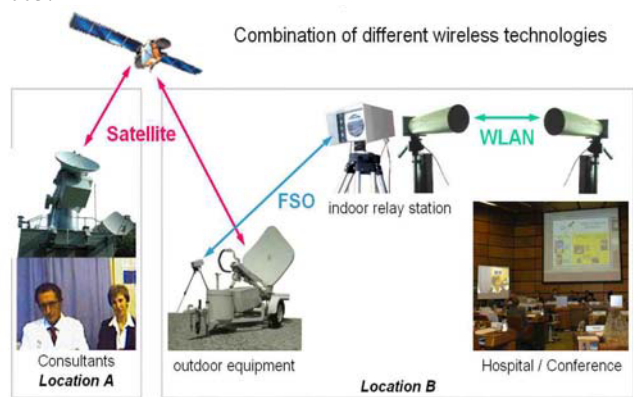


Figure 4. System setup at the demonstration at UNO-City

IV. APPLICATION AT CIMIC EXERCISE

In this section results of Free Space Optics- and Satellite applications installed at the civil-military exercise "Schutz 04" in Spring 2004 in Styria (southern part of Austria) are shown. The aim of the Austrian Army for the exercise "Schutz 04" was to get more practical experience in protection against terrorism and in civil-military-cooperation (CIMIC). The Command of a Military Division (MilDiv ST, located in Graz) is responsible not only for military operations but also for civil-military-cooperation and disaster management (together with the government of Styria and the local police command). In this exercise a mobile Satellite Earth Station (equipped with Free Space Optics and Wireless LAN) was used for Videoconferencing between military and civil organisations (police, fire brigades and departments of the government). For this purpose a fixed Satellite Earth Station was installed in the military barracks (called Gablenz in figure 6). Additional Free Space Optics-links operated with high bit-rates for data-transfer between the military division and civil organisations (police etc.). This scenario was a well suited demonstration of Broadband Communication in CIMIC. The network installations are shown in figure 5.

On April 19th, 2004 the scientists from TU Graz started their installations at noon. Free Space Optics systems were installed on the top of the building of the staff department of the Styrian Military Division Command and the neighboured buildings for generating an FSO-network. The developed Free

Space Optics systems are able to transmit with 10 or 100 Mb/s over different distances. The small FSO unit with 3 Light Emitting Diodes is used up to 100 m, whereas the larger FSO unit (with 8 Light Emitting Diodes) is used up to 300 m and (with 8 Laser Diodes) up to 700 m.

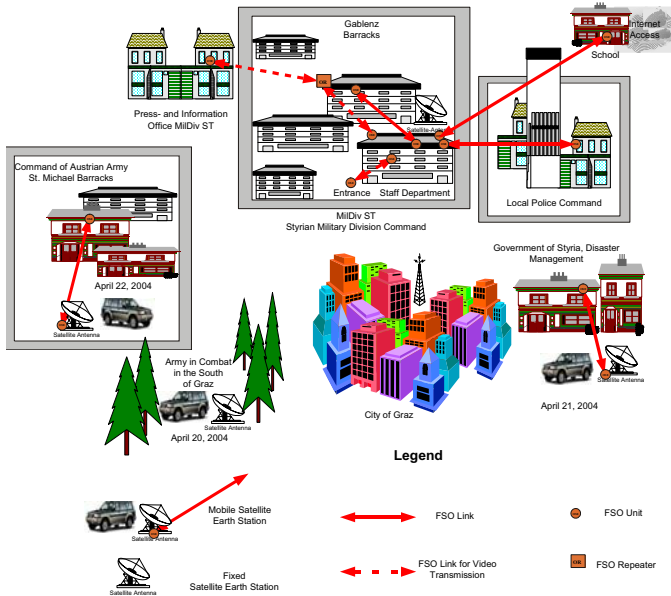


Figure 5. Network setup for the CIMIC exercise

The link budget of the FSO links was calculated in order to overcome dense fog. In the meantime a moveable Satellite Earth Station was installed at the top of staff department building (figure 6).



Figure 6. A fixed Satellite Earth Station and a FSO system at the top of the building of the staff department MilDiv ST

The team of the TU Graz and soldiers of the MilDiv ST installed together the Satellite Earth Station. The Video Conference system was established in the first floor, where the Staff Department for Operations and Planning was located. The next days (20th – 22nd of April 2004) the mobile Satellite Earth Station was used for different missions. The system allowed a data rate of 2 x 1 Mb/s using the SESat Satellite. For demonstrating a network connection via satellite, the PC at the Earth Station was supplemented with a printer and scanner, for transmitting maps, layouts etc.

A. Installation of the FSO-Network

After installing the FSO systems the scientist of the TU Graz and the two Telecommunications Officer of a territorial infantry battalion connected the systems to a small independent network (figure 7). For this purpose PCs from the government of Styria were used for connecting the FSO units to a real network. A PC with higher capacity was installed as server for this network. Bidirectional data links with Free Space Optics were realised from MilDiv ST to the Reconnaissance Battalion (130 m), to the neighbored Command of Police (300 m) and to a school (500 m). With this connection at the school Internet Access was provided to the whole network. The developed FSO systems were equipped with Fiber- or RJ-45 Ethernet Interface.

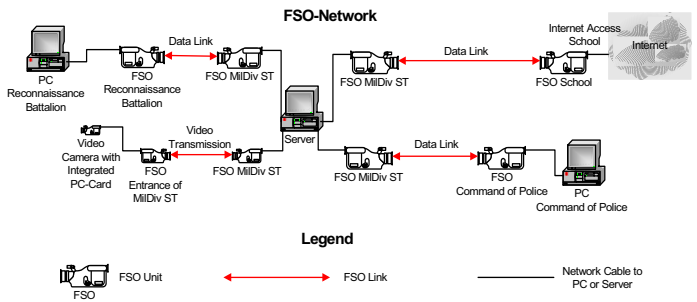


Figure 7. Free Space Optics Network at the MilDiv ST

One FSO link (100 m) located at the entrance of the MilDiv ST (at the guard-house) was used for Video Transmission. A Video Camera (with a PC-card) sent pictures from this critical point of the barracks to the Staff Department for Security of MilDiv ST.



Figure 8. Two types of the used FSO systems

B. Demonstration of the mobile Satellite Earth Station

The Satellite Communications system was used 3 days (from April 20th to 22nd, 2004) for different missions. At the first day the mobile Satellite Earth Station provided network access for an operation of the Austrian Army against terrorism near Graz. In this case the Video Conference system was installed in the car directly, because of the necessary flexibility in combat (the time for setting up the mobile Satellite Earth Station is very short). The commander of the MilDiv ST informed his staff in the Gablenz Barracks about the next steps of the military operation.



Figure 9. The Commander of the Austrian Infantry using the Mobile Satellite Communication for his operation

The next day the Satellite system was used for CIMIC purpose between the Command of MilDiv ST and the Department for Disaster Management of the Government of Styria. In this case the Video Conference system of the mobile station was installed in the office of the head of the Department of Disaster Management (figure 10 a). The Satellite Antenna was connected with Free Space Optics and WLAN to the Video Conference system. The head of the Department of Disaster Management and the Military Information and Contact Officers discussed the situation and positions with the commander of the MilDiv ST and his staff in the Gablenz Barracks.



Figure 10. Video Conference for a) CIMIC and b) military use

The last day the mobile Satellite Earth Station was used again for military purpose. The mobile Satellite Earth Station was transported to the Alpine region of Styria to St. Michael, where the Command of the Austrian Infantry was located for the exercise "Schutz 04". The Satellite system was used for a Video Conference between the Command of the Styrian Military Division (MilDiv ST) and the Command of the Austrian Infantry. The system of the mobile station was installed in the office of the head of the Staff Department for Telecommunications (figure 10 b). Like the day before, the Satellite Antenna was connected with Free Space Optics and WLAN to the Video Conference system. So the different commands could discuss problems and send maps, reports and documents in regard to their planned steps of the next missions. The maps can be shown by using the camera or are scanned first and then printed at the other side of the network link.

V. CONCLUSIONS

Broadband mobile access with IP networking technologies was demonstrated without the use of terrestrial infrastructure. The combination of different wireless technologies, Satellite Communications, FSO and WLAN shows good performance and interoperability in the complete installation. The advantages of each technology are used, GEO satellites for a worldwide backbone, FSO for easy fixed wireless connections independent of the network protocol, and WLAN for access to several mobile users. For efficient system integration however, deeper insight into the characteristics of each technology is essential, because more than just putting together devices is needed. The realized system concept presented in this paper was successfully demonstrated at several occasions.

The demonstration at the exercise "Schutz 04" has shown that combination of different wireless technologies can be used for disaster recovery and disaster management for military and CIMIC purposes.

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