Communication in Transportation Systems applying Optical and related Microwave Techniques

Otto Strobel & Jan Lubkoll

Abstract— **In the last decades optical data transmission has spread from telecommunication to many more fields. Automobile and aviation applications are common. Like in telecommunication data rates are rapidly rising. Optical data buses in vehicles are almost exclusively used in the infotainment domain: MOST (Media Oriented Systems Transport). Current data rates are in the order of 150 MBit/s. Therefore light emitting diodes (LEDs) and polymer-optical fibers (POF) as well as silicon detectors are used. In airplanes lightning strike protection raises new problems due to the future replacement of the metal fuselage by carbon fiber. According to larger link lengths instead of LEDs and POFs vertical surface-emitting lasers (VCSEL) and polymer-clad-silica (PCS) fibers are more suited. In addition data rates can be extended into the GBit/s region. This new setup enables the use of optical data transmission in automotive applications for sensors as well. Thus, safety-relevant operations like drive by wire, brake by wire and engine management can be included as well. Moreover, Optical Wireless Communication (OWC) also WLAN and Radar systems and combination of optical and microwave techniques could be a promising solution to modern challenges in telecommunication.**

Index Terms— **Optical data bus, MOST, OWC, WLAN, RoF, Radar.**

I. INTRODUCTION

The idea of this paper is to present optical and microwave systems. The optical fiber is the most common medium for modern digital optical communication which permits transmission over long distances at high data rates. It typically consists of a transparent core surrounded by a transparent cladding material with a lower refraction index. Light is travelling in the fiber core by total internal reflection. Moreover, it is possible to select glasses with sufficiently matched thermal properties; it is likely that hot embossing of glass-based matrices offers an extremely promising route for producing high-resolution, guided-wave optical components and circuitry at low-cost, high volume, and for a wide wavelength range [1].

There are fiber lasers with an active gain medium applying rare-earth doped elements such as erbium, ytterbium, neodymium, dysprosium, praseodymium and thulium. They are related to doped fiber amplifiers which provide light amplification without lasing. Diodes which are electrically pumped are semiconductor lasers such as GaAs and InP. Vertical cavity surface-emitting lasers (VCSELs) are semiconductor lasers emitting perpendicularly to the surface of the wafer.

Broadband network architecture uses optical fiber to replace all or part of the usual metal loop for last mile communications. In outer space, the communication range of free-space optical communications is currently in the order of several thousand kilometers, but has the potential to bridge interplanetary distances of millions of kilometers, using optical telescopes as beam expanders. The word ?fiber? is a synonym for the future, speed and quality.

But communication systems are also used for recent application areas in the MBit/s region, e.g. in aviation, automobile and maritime industry. Therefore - besides pure glass fibers, polymer optical fibers (POF) and polymer-cladded silica (PCS) fibers have to be taken into account.

Moreover, even different physical layers like optical wireless and visible light communication can be a solution. We show the successful transfer of a HD-Video stream over visible light via white LEDs. The electrical properties of the signal have been discussed (voltage, frequency, bandwidth and more). This is important for building the physical layer. Based on this experiment in future a visible light communication system with up to 100 Mbit data rate will be developed.

Instead of optical wireless techniques we also use microwave wireless ones: WLAN-Systems. Moreover, combinations between fiber-optic and microwave techniques have been developed, Radio over Fiber (RoF)- and Radar-Systems.

II. FIBER OPTIC TECHNOLOGIES

Since the beginning of the sixties, there has been a light source which yields a completely different behavior compared to the sources we had before: This light source is the LASER. The first realized laser was the bulk-optic ruby laser [2]. Short time after this very important achievement diode lasers for use as optical transmitters have already been developed. Parallel to that accomplishment in the early seventies, researchers and engineers accomplished the first optical glass fiber with sufficient low attenuation to transmit electromagnetic waves in the near infrared region [3]. The photodiode as detector already worked, and thus, systems could be developed using optoelectric (O/E) and electrooptic (E/O) components for transmitters and receivers as well as a fiber in the center of the arrangement (Fig.1). These systems can operate as transmission links with bit rates up to 40 Gbit/s [4].

Concerning fiber-optic transmission systems we have in particular considered the basic components. The reader should be familiarized with fundamental optical techniques for communication systems.

However, for more comprehensive considerations there are further components to be dealt with , e.g. the optical amplifier to enhance the link length over the conventional limits described above. In order to do that, mainly Erbium and Raman

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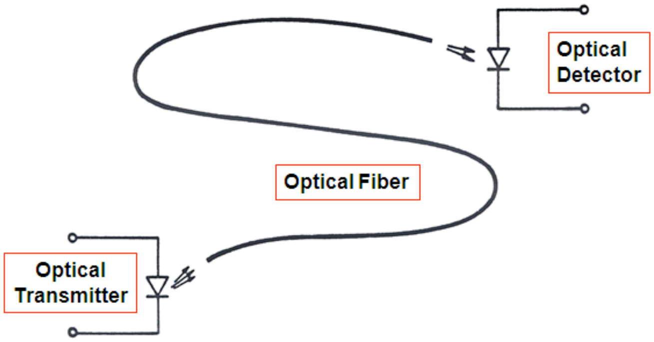

Fig. 1. Basic arrangement of a fiber-optic system.

amplifiers [5-7] have been developed to overcome the problem of attenuation in fibers. Moreover, it is also necessary to avoid signal distortions caused by the dispersion mechanisms in optical fibers. The solution to that problem could be the use of soliton transmission [8, 9].

Furthermore, Orthogonal Frequency Division Multiplexing (OFDM) is an attractive technology in wireless and wireline communication for next generation ultra high bitrate optical transmission systems [10, 11]. For very high data rates such as over 40 Gbit/s, polarization problems in fibers have to be considered. There is a further distortion called ?polarization mode dispersion (PMD)? which leads again to pulse broadening and therefore to bandwidth reduction with impact on the transmission capacity, the product of bandwidth and fiber length [12, 13].

In this paper mainly point-to-point links are discussed. Further applications for future optical systems must be taken into account - such as optical networks [14 16] (LAN and MAN).

Finally, the subject of opening up the last mile for fiber communication is of great interest. Yet, more than twenty years this idea of fiber to the home (FTTH) is discussed but it is still too expensive and therefore still waiting to reach widespread commercial market. Maybe polymer optical fibers (POF) [17] with sufficient low attenuation and gradient profile together with high-speed LEDs [18] could solve this problem in the near future. But even large core step-index polymer optical fibers (SI-POF) systems are also recently developed for in-home application [19]. It is an advantageous alternative medium to implement domestic data networks for distributing video, audio and data information.

Moreover, we present the state of the art and next-decade technologies for optical data buses in automotive applications. MOST (Media Oriented System Transport) is the optical data bus technology currently used in cars. MOST 150 is the current standard as adequate solution for optical multimedia data transmission in automobiles. However, to provide the next step to autonomous driving new bus systems with higher data rates are desirable.

Additional challenges arise in new generation aircrafts. Due to safety problems in data transmission, an optical solution for data transmission is highly needed. In particular, low attenuation PCS-fibers combined with less temperature critical VCSELs could be a promising solution. This combination paves the way for the new generation aircrafts covered by carbon fiber fuselages having a much better lightning protection and EMC-compatibility.

A FlexRay protocol has been investigated to validate the communication system for avionics. All performance criteria need to be thoroughly tested and analyzed. In order to do so, the FlexRay software stack was configured for optimized usage of CPU memory and time. The FlexRay cluster and nodes have been designed to suit the system test requirements, follwed by the system test under standard avionics test environment. It can be cost-effective and also reliable once its suitability is confirmed. Hence, FlexRay communication systems could be a good solution for avionics field bus systems.

Actually MOST for cars is exclusively used in the infotainment domain. Current data rates are 150 MBit/s. Consequently, the use of LEDs and polymer optical fibers (POF, Fig.2) is sufficient. For higher data rates, alternative solutions are discussed, too: The LED as transmitter can be replaced by a vertical surface emitting laser (VCSEL), and the polymer fiber (POF) by polymer-cladded silica (PCS) fiber [20]. Due to the inherent fact that, as a result, the fiber diameter is reduced, the detector area of the well-known Silicon photo diodes can also be reduced greatly. As a consequence, data rates can be extended into the Gbit/s-region.

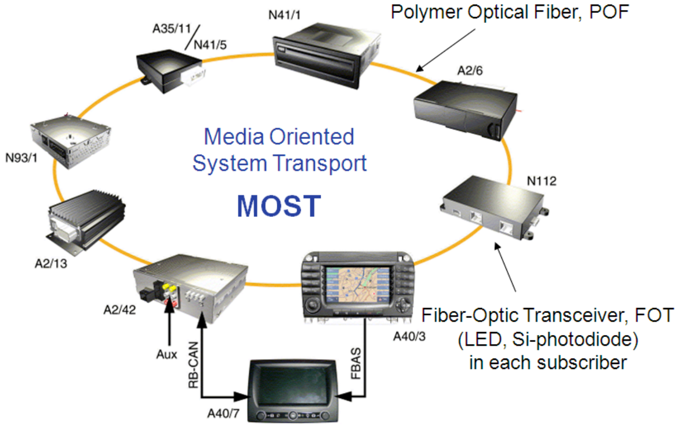

Fig. 2. MOST network with ring topology.

III. Optical Wireless Transmission of HD-Video using Commercial Illumination Equipment

We investigated a first concept for indoor wireless visible-light communication up to 100 Mbit/s by use of on-off-keying [21]. The link is based on a thin-film high-power phosphorescent white LED and offline signal processing of discrete multitone signals. The transmission at brightness levels of 400 lx and more has been investigated. Our results aim to provide up to 100 Mbit/s communication using VLC. Figure 3 shows the room and its dimensions. Arrays of LEDs will be placed on the ceiling of the VLC area in such a way that it is homogeneously illuminated. In addition to illumination these LEDs will be used for data communication.

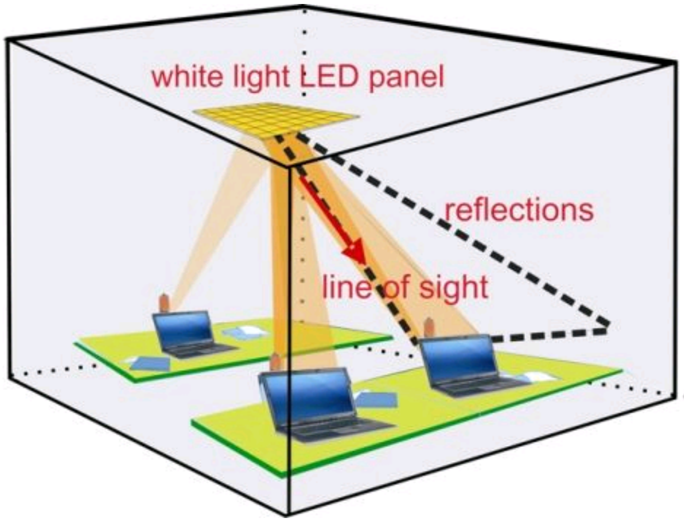

Fig. 3. One of the possible models for VLC broadcasting with an array of LEDs. These arrays of LEDs are placed on the ceiling of a room and are used for lighting as well as data communication.

Wireless communication is the fastest growing segment of the communication industry. From satellite transmission, radio and television broadcasting to mobile telephone applications, wireless techniques have revolutionized the communication in our society [22]. The need for higher data rate in wireless access network, wireless multimedia applications and wireless video is growing. Actually radio technology has been used for offering these services. However, due to the limited unlicensed bandwidth and increasing traffic the radio spectrum is becoming increasingly congested.

On the other hand, optical wireless communication provides a cost-effective, flexible solution to the emerging challenges that system and service providers are facing [23]. Optical wireless communication is primarily an indoor technology having the potential to be used as a medium for short-range high-speed wireless communications (OWC [24, 25]). Thus, OWC is an attractive supplement for the existing radio technologies.

Optical wireless communications can be, for instance infra-red communications and/or visible-light communications [24, 25]. IR communication for e.g. Infra-Red Data Association (IrDA) is widely spread in applications like notebooks, cell phones, etc. Visible-light communication promises numerous applications. Room lights can broadcast alarms, smart-home application messages or transfer files. Billboards may transmit messages. Brake-lights of a car may send warnings to a follower in case of an emergency brake action. In addition, VLC uses frequencies differing from radio frequencies. Moreover, they are license-free till today. The most appealing feature of VLC is that the same sources can be simultaneously used for lighting, signaling and display as well as for data communication.

IV. DEMONSTRATOR

A block diagram overview of a simple VLC Physical Layer is shown in Figure 4.

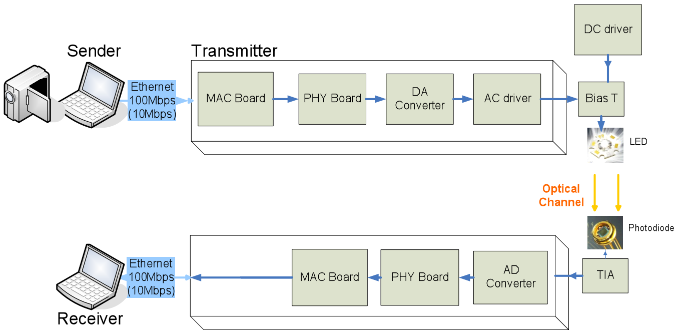

Fig. 4. Block diagram overview of VLC PHY.

The VLC PHY consists mainly of a digital and an analogue transmitter, as well as an analogue and a digital receiver. The digital transmitter consists of a data source, a baseband modulator and a digital-to-analogue converter (DAC). Similarly, the digital receiver contains an analogue-to-digital converter (ADC), a baseband demodulator and a data sink. The analogue transmitter includes an LED driving circuit (trans-conductance amplifier, TCA [26]) and a visible-light source via LEDs. The receiver includes imaging optics, a photo diode, a trans-impedance amplifier (TIA) and a band-pass filter.

Various modulation schemes have been investigated. Non-return-to-zero on-off-keying (NRZ-OOK) has been used for this demonstration [28]. This scheme has the advantage of simplicity and good immunity to LED non-linearity.

The experimental setup is shown in Figure 5. The 20 dB coupler has been incorporated into the test setup. Thus, we are able to realize the signal display on an oscilloscope without high signal loss.

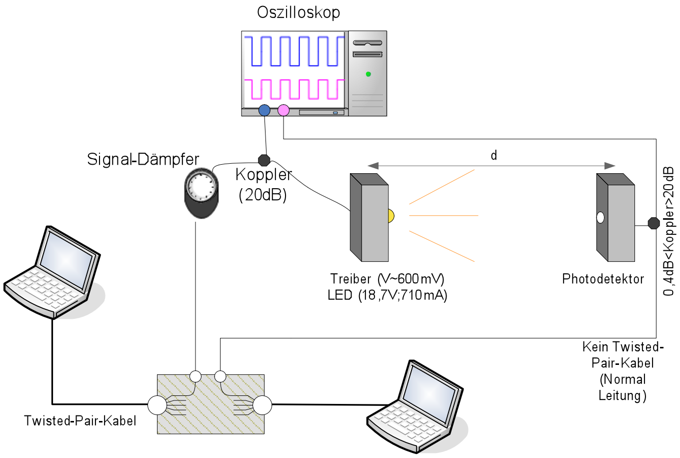

Fig. 5. Experimental setup with variable Tx-Rx distance.

The measurements results for a data transfer of 10 Mbps Ethernet signal sequences are summarized in Table 1. The results show that a transfer of video streams via optical channels is possible.

TABLE I
MEASUREMENTS RESULTS OF A 10MBPS ETHERNET SIGNAL.

Parameter	measured
Transfer rate	10Mbit/s
Bandwidth	17MHz
Voltage ca.	(-1,+1)V
Encoding	Manchester
Modulation rate	5MHz
Clock frequency	10MHz

V. FEASIBILITY STUDY OF AN AUTOMATIC TRAIN CONTROL SYSTEM USING A MEDIUM ACCESS LAYER IN A WLAN OVER FIBER ENVIRONMENT

We present the design of optimum WLAN-Settings for maximum throughput or respectively minimum of collisions in a WLAN over fiber system [29]. The fiber delay might violate some of the timing boundaries of the media access (MAC) protocol. If we chose a careful slot time these networks are operating properly without the need for modifying the existing protocol. The network topology is based on a WLAN-Environment that is used in a subway in Nanjing (China) to accomplish the Trainguard MT System.

Radio over fiber (RoF) technology enables both, distribution of wireless signals over long distances and reducing costs of antenna sites, since the signal processing can be done at a central point [30]. The 802.11 standards were developed for WLANs which operate in relatively small areas not suffering from significant signal delays. Normally the propagation delay in air is much smaller than 1 μs. In WLAN over fiber systems additional delay time occurs. The propagation time is the sum of the air propagation delay and the one caused by the propagation through the fiber.

VI. SYSTEM DESCRIPTION

Under continuous communication or point-communication conditions the Siemens Automatic Train Control (ATC) system ensures train safety and continuous supervision. The safety of train separation is based on the moving block principle [31]. The ATC sets two terms on data stream. The throughput for the ATC has to be 10 kBit/s for downlink and 1 kBit/s for uplink. Every transmitted frame must not be older than 10 ms. There are two typical frame sizes used by the ATC system. 30% of all frames are 170 Byte in size and 70% are 220 Byte in size. The used WLAN standard is 802.11b. Therefore the maximum throughput is 11 MBit/s.

RoF makes use of the concept of a Remote Antenna Unit (RAU). This unit exclusively consists of an optical-to-electrical (O/E) and an optional frequency up or down converter, amplifiers and the antenna. This means that the resource management and signal generation circuitry of the Central Site (CS) can be moved to a centralized location and shared between several remote stations. Thus, the architecture is simplified (see Figure 6).

By use of an optical splitter more than one RAU can be connected to a single CS. All the connected RAUs build a wider area which is covered by a single Access Point (AP). Due to the existing topology a fiber length of 2 km is intended.

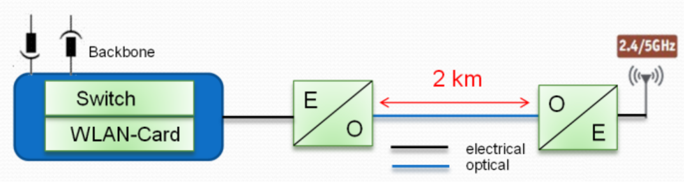

Fig. 6. RoF-Components.

VII. INVESTIGATIONS ON COMMUNICATION FOR AUTOMOTIVE SYSTEMS USING 4G WIRELESS TECHNOLOGIES

We are using 4G wireless technology in the car based on new services and business models [32]. This is enabled by ultra-high bandwidth technology, always-on network connectivity, cloud computing, cloud storage and value-added network assets such as content management. Furthermore, we apply location services, presence, identity, security, billing and innovative in-vehicle hardware and software systems. This service package provides always-on access to the internet, along with entertainment and real-time navigation systems (Figure 7).

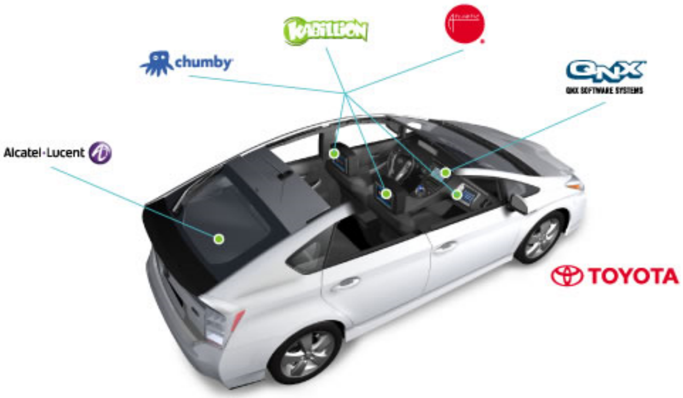

Fig. 7. Fig. 7 Toyota Prius, “LTE Connected Car”.

Standard features include:

- Access to social and communication information as well as streamed radio, TV and video content.
- Live updated information about traffic and locations of interest.
- Accident and emergency assistance combined with stolen vehicle recovery systems.

Enhanced features include:

- Screens in front and rear of the vehicle.
- Wi-Fi access for portable devices.
- Device integration for mobile phones, media players, gaming and computers.
- Live map data.
- Video and audio services, such as on-demand movies and access to TV and internet video.
- Location-based services, including Google Maps.
- Communication and messaging service access.

- Remote vehicle diagnostics, maintenance tracking and notification systems.
- Natural language voice interaction for safety.

VIII. APPLICATION PLATFORM

Millimeter-wave frequency bands offer several distinct advantages in vehicles for providing the capacity and flexibility in applications needed by emerging broadband communication system initiatives. Channel characteristics in this frequency range call for special attention being given to system design. RF channel induced mutual fluctuations between the carriers are of fundamental importance. Therefore we employ a modulation technique relying on the synchronization or orthogonal relation between carriers and subcarriers. Laboratory measurements have been carried out on a broadband millimeter-wave communication system. The measurements show that fluctuations caused by the equipment are only significant in raising the background noise. This happens in a heterodyne signal caused by the carrier pair at 28 GHz separated by 40MHz. Therefore, a carrier-to-noise ratio of over 30 dB can be sustained. The experiments prove that the current millimeter-wave technology is effective in providing support for broadband information access with significant throughput and spectral efficiency.

IX. HARDWARE PLATFORM AND EXPERIMENTAL RESULTS

Subscriber device switching between base stations in the 4G network happens during 40 ms, allowing full access to the network. We carried out experimental investigations with a car at speeds up to 140 km/h. The system we used was an ordinary 4G USB Modem Samsung SWC-U200 connected to a simple netbook. The program we applied was Yota Access. Thus, we were able to measure the CINR (Carrier to Interference and Noise Ratio) and the RSSI (Received Signal Strength Indication).

Carrier to Interference-plus-Noise Ratio (CINR), expressed in decibels (dB), is a measurement of signal effectiveness. The carrier is the desired signal, and the interference can either be noise or co-channel interference or both. Regarding the receiver the signal must fall into an acceptable CINR range for decoding. The range differs from the applied technologies (i.e. CDMA, GSM, etc.). The RSSI values don?t feature a unit and in the range 0 to 255, expressible as a one-byte unsigned integer. The maximum value, RSSI_Max, is vendor dependent. For example, Cisco Systems cards have a RSSI_Max value of 100 and will report 101 different power levels, where the RSSI value varies from 0 to 100. Another popular Wi-Fi chipset is made by Atheros. An Atheros based card will return an RSSI value of 0 to 127 (0x7f) with 128 (0x80) indicating an invalid value.

From Table 2 we see that at speeds up to 140 km/h, we can send and receive data signals up to 10 Mbs without disconnection to the base station.

The system based on network infrastructure can be arranged via VPN-connections over the internet or via dedicated channels between a local company network and the network infrastructure.

TABLE II
CINR AND RSSI AT DIFFERENT SPEED

Speed (km/h)	CINR (dB)	RSSI
30	30 …21	-48…-62
60	28 …16	-41…-65
80	30…20	-52…-55
100	20…8	-62…-80
120	31…12	-46…-69
130-140	28…9	-48…-75

Where it is of interest?

- In taxi business and corporate coaches for passengers to access the internet;
- in car accident and emergency services for video conferencing with operational headquarters;
- in ambulances for the organization telemedicine;
- in mobile radio and video studios for the organization of online broadcasting everywhere in the area of coverage.

X. RADAR SYSTEMS

Radar systems can possibly be used to review conditions of limited optical visibility [33] (fog, snow, rain, high smoke content etc.). Possible application areas are: control of movement of ground vehicles, search landing places for planes and helicopters and search for objects of natural and artificial origin on earth. Furthermore the system can be used for visual control or for other situations where optical or IR-gauges are too difficult or impossible to use.

Radar systems working in a resolved frequency range. Moreover, they do not influence other radio-electronic devices. One practical application is the automobile radio vision system. It generates a radar-tracking image of the road. This gives the driver an opportunity to observe precisely road borders, cars, other subjects and obstacles within the limits of the working range even if there is no visibility (Figure 8).

FIGURA 8

XI. CONCLUSIONS

We presented a brief introduction to optical and related microwave transmission systems. Pure-optic and fiber-optic transmission systems have been taken into account. Principle operations and first promising experimental results in telecom and automotive applications have been shown. Furthermore, applying optical and microwave techniques a Radio over Fiber (RoF) System has been investigated. A simulation has shown that WLAN over fiber can be realized and finally it has been proofed that a common MAC-Layer can be used in a WLAN over fiber scenario. Also pure microwave techniques are of interest. Radar systems can possibly be used to review conditions of limited optical visibility. Finally we want to remark that the customer nowadays wants a complete solution for his demands and he does not ask if that is fiber optics or what ever. Therefore, combinations of various physical techniques with or without fibers, optical and non-optical solutions have to be developed.

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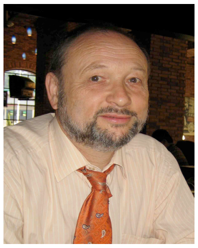

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