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The work of Project 1032 of the RACE program definition phase is summarized. The background and problems relating to coherent multichannel techniques for integrated communications subscriber lines, assumptions, and recent relevant state-of-the-art developments are discussed, including a commentary on Level III of the RACE definition phase scenario (ROPS-3). Key words!

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COHERENT MULTICHANNEL TECHNIQUES FOR INTEGRATED BROADBAND COMMUNICATIONS SUBSCRIBER LINES

This report summarizes the work of Project 1032 of the RACE Definition Phase (see *ONRL Report* 8-014-R for information on the RACE program) which was carried out by Heinrich Hertz Institut GMBH, West Germany; AEG Aktiengesellschaft, West Germany; Philips Laboratory, the Netherlands; and Plessey, UK.

A common assumption for integrated broadband communication networks (IBCN's) is that optical fiber, particularly single-mode fiber, will be the main transmission medium within the future IBCN. Also, digital signals will have to be transmitted and switched.

At present the capacity of optical fiber subscriber loops is limited so that the distribution of TV programs can only be performed by means of switching techniques within the central office.

As in radio communication evolution, it is to be expected that evolution towards coherent optical techniques using heterodyne receivers for optical transmission systems will occur. Systems with direct detection convert directly the digital intensity modulated input signal by means of a photodiode to an electrical signal which is amplified and regenerated. The input signal of an optical heterodyne receiver is a modulated optical wave of a determinate carrier frequency f_c. This wave may be amplitude, phase, or frequency modulated. It is fed to a photodiode by way of a directional coupler together with an optical wave of frequency f_l generated by a local laser. The response of the photodiode is an electrical beat frequency which corresponds to the frequency difference of the two optical waves. This intermediated frequency (IF) signal can be filtered amplified, demodulated, and regenerated by electronic methods.

One advantage of coherent optical transmission is that optical heterodyne receivers are, depending on wavelength and modulation scheme, by 10 to 20 dB more sensitive than direct detection receivers. This feature is useful for long- distance transmission systems for repeaterless bridging of very long distances. For the local network the better power budget available permits a high degree of laser sharing in the central office for distribution services implementation.

Another advantage of optical heterodyne receivers is their high selectivity. Due to the high selectivity of the microwave IF filters of these differences of only a few GHz can be selected. In the optical wavelength region of 1.3 to 1.55 μm the window of 2500 angstroms has a bandwidth sufficient for about 20,000 carriers of 2-GHz carrier difference. Even through this number of carriers is not practical, systems with several hundreds of carriers appear to be achievable. Thus there is no relevant limit with respect to the number of channels for the application of coherent multichannel techniques for IBCN applications.

A further useful feature of the optical heterodyne receiver is that the local laser can be tuned over a wide frequency range so that each carrier of a multichannel system can be easily accessed. This leads to transparent and flexible systems since the features of each carrier can be determined independently from those of the other carriers. Thus, the implementation of a new service with new standards would mean only adding one or two carriers to the subscriber system and not the redefinition of, or the adaptation to, existing time division multiplex (TDM) structures. It is also possible to assign several TDM channels to a coherent carrier, or to assign groups of coherent channels to frequency bands, which can be separated by means of conventional wave division multiplex (WDM) techniques. Also, switching functions can be implemented in the coherent multichannel system.

Recent relevant developments in the state of the art include:

- Single-mode lasers, a prerequisite for stable and tunable coherent optical sources, are available
- Distributed feedback (DFB) lasers with separate electrodes for tuning or frequency modulation are under development
- A method for building single-mode coupling networks with large numbers of inputs and output has been found
- Single-mode fiber star couplers with 16 inputs and outputs are commercially available
- Also available are single-mode wavelength-independent couplers (1.2-1.6 μm) and single-mode wavelength-division coupling elements (1.3/1.5 μm)
- Laboratory coherent long-haul transmission systems have been developed in recent years
- Investigations have shown that in the four wave mixing effect, critical for multicarrier systems, fiber nonlinearities will have no impact on subscriber line systems
- Crosstalk due to the stimulated Brillouin scattering effect can be avoided by providing a high-frequency gap between counter-propagating optical waves.

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- Single-mode fiber will be used for both long distance lines and for subscriber systems of future public networks.

Coherent multichannel may be one of the options for a future IBCN and this will strongly influence the subscriber line, the subscriber premises network and the facilities for the distribution of broadband signals in the central office.

The scenario for IBCN assumes that up to 100 TV programs have to be distributed and that about 10,000 subscribers are connected to one central office. While single-mode fiber will be employed for subscriber lines, the topology of the local network is of the star type. Generally, no switching functions are required for distribution services of high definition television (HDTV), and other future broadband services are not restricted to a maximum channel bit rate of 140 Mb/s.

It is assumed that initial implementation of the IBCN will use direct detection technology. The first level of the RACE definition phase scenario (RDPS) represents the introduction of coherent multichannel communications (CMC) techniques to provide broadband distribution services such as TV, the second level includes access to network specialized centers, and in the final level directional broadband links will use coherent transmission.

Level III of RDPS-3

For the final level it is assumed that coherent optical transmitters and receivers are available as consumer production components, so that CMC techniques can be used throughout the local network and within the subscriber premises network. It is further assumed that the 1.5-μm wavelength region is used. Two main functional aspects of final level network for residential use are:

- Each private subscriber is connected with the central office by a subscriber optical coupling network (SOCN), consisting of the office coupling network, the optical fiber, and the optical subscriber premises network. The SOCN is considered as an optical bus which provides both downstream and upstream transparent optical connections between the coherent transceivers in the central office and the coherent transceivers of the subscriber terminal equipment.
- No switching functions are required for the implementation of distribution services. It is possible to establish a large number of separate channels and due to the power budget, a high degree of laser sharing is allowed. The multi-channel-transmitter unit (MCTU) could be equipped with high-power distributed feedback (DFB) lasers which feed the distributive optical coupling network (DOCN). It is estimated that, depending on the TV or HDTV bit rate, one MCTU can supply though the DOCN about 1,000 to 10,000 subscribers.

The switching functions for terminal equipment or network specialized center connection can be performed with any switching technology available at the time of implementation. The introduction of CMC subscriber line systems has no direct impact on the dialogue broadband switching techniques. However, CMC techniques may be an option for broadband dialogue switching networks.

RDPS phase 1 assumes for business applications a subscriber premises network (SPN) with 100-500 terminals. RDPS-1B is an earlier and different scenario for an IBC network. The capacity of an RDPS-1B subscriber line amounts to four broadband channels. This is not sufficient for the business type of SPN which has to support a large number of subscribers. CMC techniques can provide the adaptability of future IBC networks to SPN's with a large number of connected subscribers. In order to accommodate more dialogue connections, the office coupling network (OCN) and the optical subscriber premises network (OSPN) have a large number of fiber ends. However the number of fiber ends is limited. Assuming FSK modulation, an optical input power of 0 dBm coupled into each fiber end, and the same channel capacity as provided by RDPS-1B, power budget calculations show that up to 37 fiber ends could be applied. In this case the total capacity of a one-fiber link amounts to about 20 Gb/s for each direction.

If the passive coupling network for OCN and OSPN are provided, channels with different bit rates can be added easily to the existing business subscriber systems as required. Channels with bit rates higher than 560 Mb/s can be established by use of transmitter lasers with higher output power. Channels supporting the same service can be combined by means of time division multiplexing (TDM) techniques to one coherent channel. In order to keep the hardware required for the multiplexer/demultiplexer functions as low as possible, very simple TDM should be chosen.

If required, distribution services can be included in business systems by feeding one OCN input of the respective subscribers with the DOCN carrier signals. Since a residential SOCN has lower attenuation than a business DOCN the DOCN must provide outlets with higher output power for business subscribers. These can be implemented by using a lower number of expansion stages of the DOCN.

Business Subscriber Premises Networks (B-SPN), which have to support many terminals, cannot be implemented by directly connecting the fibers of the OSPN to the terminals. There must be a gateway between the coherent multichannel IBCN access and the internal communication system of the business subscriber. This subscriber-specialized network may be either multichannel coherent or a high bit rate TDM system.

Level I and II of RDPS-3

During the IBCN evolution many potential residential users will want to use some of the narrowband ISDN teleservices, e.g., telephony, videotex, and PC support. These subscribers may be interested in the IBC audio and video distribution services. If they are connected to the central office by a single-mode fiber these services can be easily implemented in Level I set up as follows:

- There are one or several multichannel transmitter units (MCTU) feeding a distribution optical coupling network (DOCN). The output fibers of the DOCN are coupled directly to the subscriber fiber. At the subscriber's premises the coherent multichannel signal is coupled out at the input of the NB-ISDN network termination NT and fed to an optical star network in order to connect the TV or audio sets. For audio distribution one coherent channel with a TDM frame containing all audio channels will be used.
- Provisions have been made to separate the NB-ISDN signals from the coherent multichannel signals, which will requires a frequency range of a few hundred GHz, preferably in the 1.5- μm wavelength region. The way in which the separation can be performed will depend on future narrowband ISDN standards.

The DOCN can be implemented with a small amount of subscriber-related hardware. The DFB lasers of the MCTU can be shared by a large number of subscribers so that a rather small number of lasers is required. This laser sharing technique can be fully used when a corresponding number of subscribers is connected to the central office. But the problem of providing the first few subscribers with broadband services in an economic way is common to all approaches. For the application of lasers in an early state of development, the coherent channels can be structured into four or eight TDM channels, each assigned to one TV program. Although this does not reduce the number of transmitter lasers, the requirements on the laser line width and on the long-term stability is reduced if high bit rates and wider channel spacing are used.

After the implementation of optical cable TV or HDTV the next step in broadband Communications could be the inclusion of broadband retrieval services such as audio library or film retrieval. The possibility for individual access to useful broadband information is one advantage of optical star networks over coaxial tree networks. Since only a downstream broadband connection is required, the broadband transport functions could be provided at lower cost that those of bidirectional broadband services.

For business applications dialogue services will be important. Since the technologies required for coherent optical communication will not be available in the first phase, only solutions based on direct detection can be considered at that time. However provision should be made for introduction of or conversion to coherent techniques in the future. Thus, it is important to employ single-mode fiber throughout the network, a prerequisite for coherent optical communications and optoelectronic integrated circuits (OEIC). To provide for simultaneous operation of direct detection and coherent communication in the same business-dedicated work, the direct detection system should not occupy the whole 1.5- μm wavelength range, but should allow for including the coherent carrier comb by WDM techniques.

Comments

CMC subscriber systems discussed herein are based on advanced optical techniques and may offer advantages in hardware and in performance. The main hardware advantage will occur in the central office in the implementation of broadband distribution services through a high degree of laser sharing. In performance, CMC subscriber systems offer greater flexibility and upgrading capability, higher reliability, ease of maintenance, and a transparent subscriber premises network. The selection of TV Channels is carried out within the TV set and not by switching in the central office. This reduces problems in connection with signaling bursts and is an important privacy advantage.

Key components for CMC techniques are electronically tunable ~~DFB~~ lasers, which should not be affected by reflections or compact laser isolator modules. The development of low-cost, passive optical components is likely to be continued in the RACE Program. The development of a CMC laboratory would be useful for studying problems connected with the combining of direct detection and CMC systems.

distributed feedback

Reference

Race Definition Phase, Scenario 3 Version III, CMC-Techniques for IBC Subscribers Lines, RDP Project 1032, European Commission, February 1987.