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Industrial automation — Time-critical communications architectures — User requirements and network management for time-critical communications systems

*Automatisation industrielle — Architectures de communications en temps
réel — Prescriptions des utilisateurs et gestion de réseau
pour les systèmes de communications en temps réel*



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Foreword

ISO (the International organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

- type 1, when the necessary support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within 3 years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13283, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Subcommittee SC 5, *Architecture and communications*.

It is becoming apparent that in their present form the OSI Standards cannot readily accommodate time-critical communications. The network architectures which have been standardized so far were primarily intended for general traffic and are not always capable of providing adequate performance and resilience for time-critical communications, especially where time-critical and non-time-critical traffic coexists. In particular in many CIM and control installations there appears to be a requirement for an intermediate network, between general enterprise-wide networks (e.g. MAP) and the fieldbus-type networks. This intermediate network should carry both bulk data transfer and time-critical messages, and be able to operate over considerable distance and in hostile environments.

A task force was therefore setup under ISO/TC 184/SC 5/WG 2 to look at requirements for a time-critical communications architecture, concentrating particularly on the requirements in intermediate network and thus complementing work done on requirements for time-critical communications in the fieldbus and to prepare a Technical Report on the topic. Among those requirements some are identified to be considered when managing time-critical communications network where the specified time window must be respected by the communication systems. The management and the support for these requirements are the second part of this Technical Report. The relationship with other standards is depicted in the Figure 1.

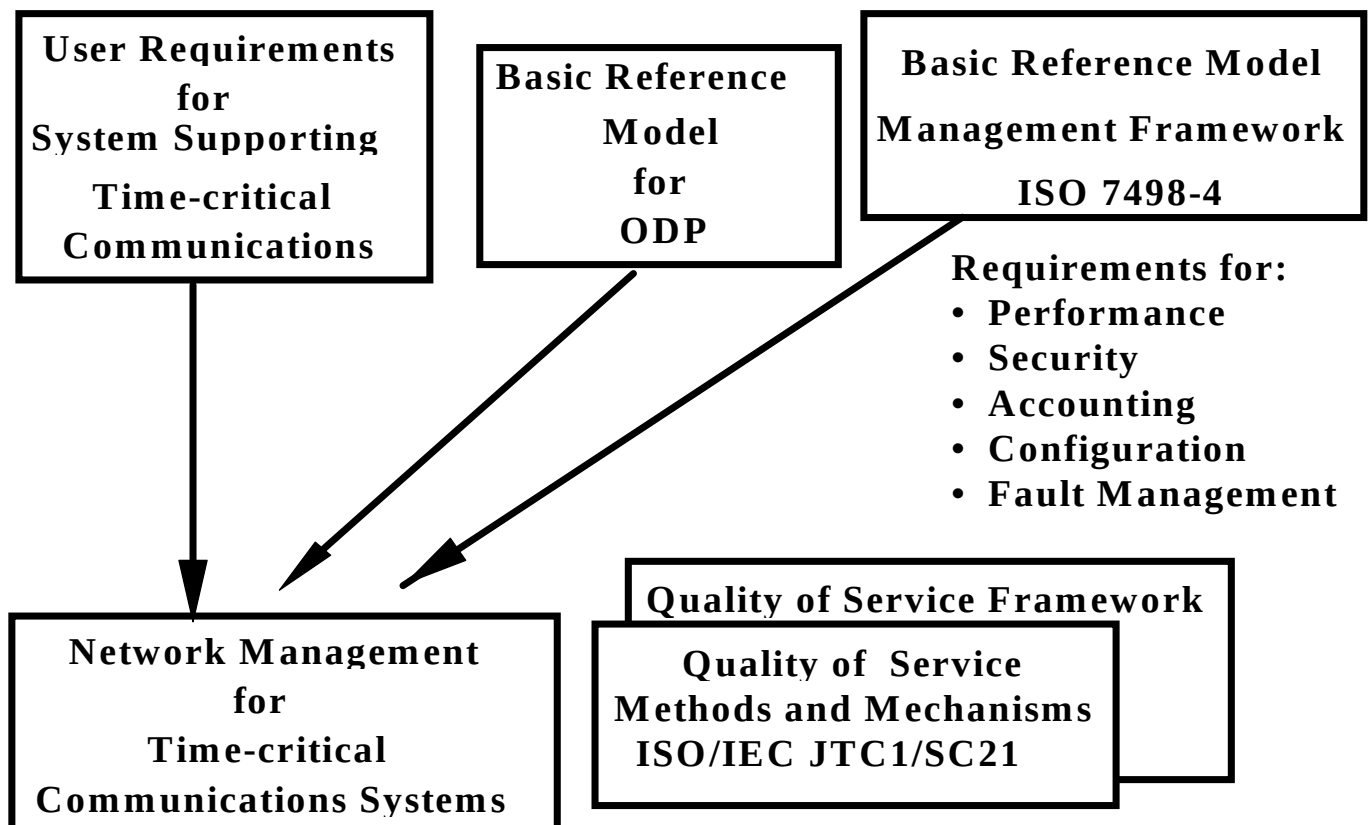


Figure 1 — Relationship with other standards

Time Critical Network Management (TCNM) defines only those additional requirements that are necessary to manage a TCCS network. TCNM does not describe the system management consideration regarding configuration management, accounting, security, and fault management except where these might be required to support the time critical aspects; i.e. support for TCNM directly impacts performance management to a great extent, but also impacts other areas which use time critical services to accomplish their function.

The focus of this Technical Report is to identify the communication needs of tightly coupled control systems, and the management and support of these needs. This effort is intended to complement efforts which have focused on factory information networks (e.g. MAP) which are characterized by high throughput, large packet service between information processors (e.g. mini-computers) and control processors (e.g. special purpose controllers). The effort is also intended to complement efforts to identify sensor networks (e.g. fieldbus) which concentrate on providing a low complexity interface to simple factory floor sensors, actuators and other devices.

There is no clear consensus on whether the time-critical communication architecture should be connection-oriented or connectionless. Either solution is acceptable providing that the requirements are met; however, some requirements may be easier to meet one of these solutions than with the other. Since MMS uses a connection-oriented session layer then the overall service may appear connection-oriented even if the network and transport layers are connectionless.

This Technical Report summarizes the user requirements for time-critical communications systems that have been identified by the task force and provides a short explanation of each of the requirements. Consideration is also given to the management and support of these requirements.

Introduction

General requirements for TCCS

A time-critical communications system (TCCS) is a type of communications network system which is optimized for communications where sequences and traffic patterns vary dynamically over a whole network system. However, such a communications network system also has to support pre-scheduled static sequences of communications.

Time-critical communications are communications in which there is a specific bounded time window within which one or more specified actions must be completed with some defined level of certainty. A TCCS provides the capability for both time-critical messages and non-time-critical messages to coexist. In a distributed time-critical application, algorithms, data and control structures are around networks. Such a distribution is only possible if the communication systems provide a certain quality of service, particularly regarding time constraints, coherence, etc.

It is recognized that all TCC systems differ from other networks in their requirement for resilience. The tighter the time constraints are, the more important strategies for resilience become, since networks capable of meeting tight time constraints need to exhibit great resilience if the data flow is not to be perturbed by minor faults.

A TCC architecture complies with the OSI Basic Reference Model whenever appropriate, meeting the user requirements identified in clause 4. Current OSI standards cannot readily accommodate time-critical communications because their primary objectives are to ensure the transfer of general data traffic or to satisfy intercommunication between delivery of messages. Therefore, the current OSI model and architecture needs to be enhanced to support TCC.

User requirements for TCCS

Automated factories use networks for distributed control applications. These applications require communications systems which are designed to accommodate worst-case performance as opposed to average performance; in such systems timeliness is of paramount importance. The network should be able to cope with both bulk data transfers and time-critical messages and should support methods for achieving resilience.

If necessary, interfacing the TCCS with the main factory data communication network should be a simple procedure, using a linking device. Because of the requirement to operate in very harsh environments, highly reliable media and signaling methods are necessary so that a very low bit error rate results and a minimum number of retransmissions is necessary. The user needs to be able to define communications priorities and control error recovery mechanisms. Network management functions are necessary to allocate resources, control access to TCC groups, detect latent failures and actual failures, etc.

The user requirements that are identified allow the concept of time windows to be realized in OSI. The inter-relationship between TCC architecture, characteristics or attributes, time windows and applications requiring time-critical communications are set out in Figure 2.

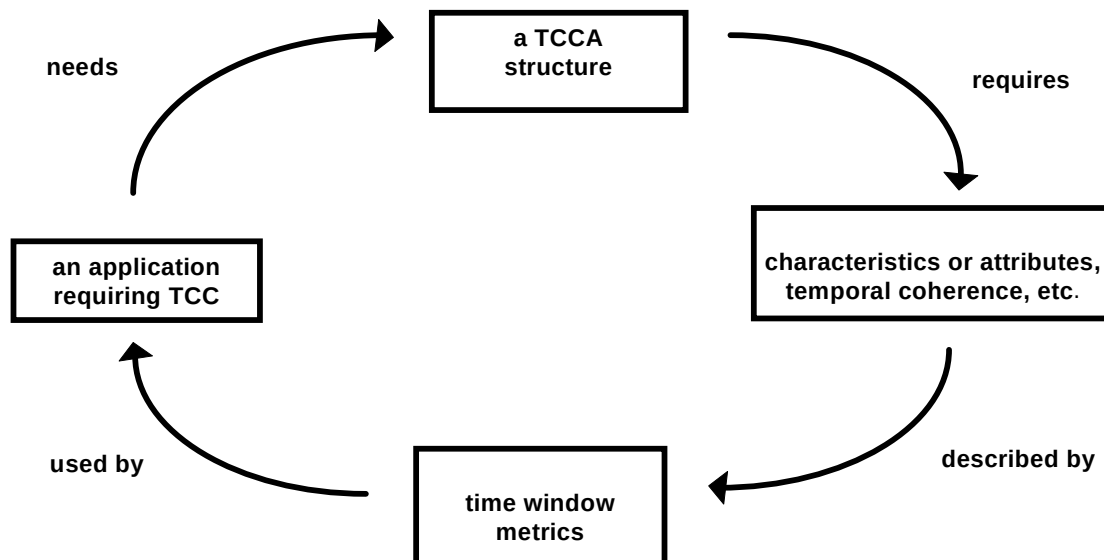


Figure 2 — Inter-relationship between TCC architecture, characteristics, time windows and applications requiring time-critical communications

Network management in TCCA

The requirements on network management are extracted and translated from the user requirements in TCCS in terms of the provision of services which is essential in order to meet the time constraints specified by users under the circumstances in which the behaviour of the time-critical communications network system varies dynamically.

In the sense of the QoS Basic Framework, the QoS requirements are information to express part or all of the network management requirements, and are expressed in terms of QoS parameters as part of a mechanism when a QoS requirement is conveyed between entities. This information closely concerns a policy that is to apply to the operation of a time-critical communications network system.

In some time-critical applications all user requirements need not always be satisfied. It is therefore not essential for a TCCA or the network management in a TCCA to meet all the network management requirements identified herein. This means that there will be allowable classes which meet specific subsets of these requirements. These classes are not addressed in this Technical Report.

Industrial automation — Time-critical communications architectures — User requirements and network management for time-critical communications systems

1 Scope

This Technical Report identifies user requirements for systems supporting time-critical communications systems and the network management aspect which are specific to time-critical communications architecture in peer-to-peer and multipeer communications in or between application processes.

This Technical Report translates user requirements for systems supporting time-critical communications into QoS requirements for the management and support of a time-critical communications network, using the concepts and terminology of the QoS Basic Framework developed by ISO/IEC JTC1/SC21/WG7.

This Technical Report also describes a model, characteristics and functions for network management in time-critical communications systems.

This Technical Report focuses on time-critical communications systems used in discrete parts manufacturing applications; however, these time-critical communications systems may also be used in other applications, including process control.

This Technical Report concentrates primarily on time-critical communications systems for event-driven applications in which traffic flow and network configuration change dynamically; however, this Technical Report may also be applicable to state-driven applications in which traffic patterns and configuration are static.

2 References

The following standards contain provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

2.1 International Standards

ISO/IEC 7498-1:1994, *Information technology — Open Systems Interconnection — Basic Reference Model: The Basic Model*.

ISO/IEC 7498-4:1989, *Information processing systems — Open Systems Interconnection — Basic Reference Model — Part 4: Management framework*.

ISO/IEC 9506-1:1990, *Industrial automation systems — Manufacturing Message Specification — Part 1: Service definition*.

ISO/IEC 9506-2:1990, *Industrial automation systems — Manufacturing Message Specification — Part 2: Protocol specification*.

ISO/IEC 9545:1994, *Information technology — Open Systems Interconnection — Application Layer structure*.

ISO/IEC 10040:1992, *Information technology — Open Systems Interconnection — Systems management overview.*

ISO/IEC 10164-1:1993, *Information technology — Open Systems Interconnection — Systems Management: Object management function.*

ISO/IEC 10164-11:1994, *Information technology — Open Systems Interconnection — Systems Management: Metric objects and attributes.*

ISO/IEC 10164-13:1995, *Information technology — Open Systems Interconnection — Systems Management: Summarization function.*

ISO/IEC 10164-20, *Information technology — Open Systems Interconnection — Systems Management: Time management function.*

ISO/IEC 10165-1:1993, *Information technology — Open Systems Interconnection — Management Information Services — Structure of management information: Management Information Model.*

ISO/IEC 10165-2:1992, *Information technology — Open Systems Interconnection — Structure of management information: Definition of management information.*

ISO/IEC 10165-4:1992, *Information technology — Open Systems Interconnection — Structure of management information: Guidelines for the definition of managed objects.*

ISO/IEC 10731:1994, *Information technology — Open Systems Interconnection — Basic Reference Model — Conventions for the definition of OSI services.*

ISO/IEC 10746-2:1996, *Information technology — Open Distributed Processing — Reference Model: Foundations.*

2.2 Documents under development

ISO/IEC JTC 1/SC 21 N 9309, *Quality of Service — Basic Framework.*

ISO/IEC JTC 1/SC 21 N 9310, *Quality of Service — Methods and Mechanisms.*

3 Terms and definitions

For the purposes of this Technical Report, the following terms and definitions apply.

3.1 TCCA terms

3.1.1

application dependent requirement

a requirement related to the usage of the time-critical communications architecture and should be independent of the implementation

3.1.2

application entity

AE

part of the application process that deals with the communications system

3.1.3

implementation-dependent requirement

a requirement which depends on the specific aspects of the implementation of the time-critical communication architecture being used

3.1.4

interaction

any causal relation induced by message transfer

3.1.5**media access control****MAC**

the data link layer responsible for scheduling and routing data transmission on a shared medium

3.1.6**multipeer data transmission**

the transmission of a PDU to one or more destinations

3.1.7**multipeer group**

a group of peer entities which are mutually willing and able to be senders or receivers of multi-peer data transmissions with other members of the group

3.1.8**performance**

the behaviour of the system with respect to time

3.1.9**spatial coherence**

a property of duplicated lists of variables indicating whether or not all the copies are identical at a given time or within a given time window

3.1.10**temporal coherence**

a property of a list of variables indicating whether or not the value of each variables in the list has been produced and transmitted and/or received within a given time window

3.1.11**time-critical communications****TCC**

when one or more application process which send a message require it to be received (or received and acted upon, or received and acted upon and confirmed) within a certain bounded time period window after its send request to the system

3.1.12**time-critical communications architecture****TCCA**

an architecture, in the sense of the OSI reference model, which supports the identified requirements for time-critical communications

NOTE TCCA is a structure which has layers, entities, service access points, protocols, connections, etc. in accordance with the concepts introduced in ISO 7498.

3.1.13**time-critical communications entity****TCCE**

an entity participating in time-critical communications (a time-critical communications entity may or may not map directly to an application entity since a single application entity could have time-critical and non-time-critical components)

3.1.14**time-critical communications group****TCCG**

a group of time-critical communications entities in a time-critical communications system

3.1.15**time-critical communications system****TCCS**

a system in which there are time-critical communications

NOTE A TCCS is an implementation of a time-critical communications architecture. The system consists both of a user's application processes and a time-critical communications network.

3.1.16

time-critical communications transaction

TCCT

an ordered set of message transfers (or exchanges) coming from different application entities which all have to be completed within a given time window

NOTE This may be a time-critical multipeer communications transaction or a time-critical peer to peer communications transaction. Such transactions are complex information processing operations involving multiple data transmissions for an application with time constraints.

3.1.17

time-critical data transmission

TCDT

the transmission of a PDU within a given time window

3.1.18

time-critical multipeer data transmission

TCMDT

the transmission of a protocol data unit to more than one destination within a defined time window or time windows

3.1.19

time window

TW

a bounded time interval which is characterized by starting time and delay or starting time and end time which are application dependent

NOTE The degree of resolution of time and delay is implementation dependent.

3.2 OSI Basic Reference Model terms

This Technical Report uses the following terms drawn from ISO/IEC 7498-1:1994: (N)-layer, (N)-protocol, (N)-protocol-data-unit, (N)-service, (N)-service-access-point, (N)-subsystem, open system, and OSI environment.

3.3 Service convention terms

This Technical Report uses the following terms drawn from ISO/IEC 10731:1994: (N)-service-facility, (N)-service-provider, (N)-service-user, requester, and acceptor.

3.4 Basic Reference Model of Open Distributed Processing terms

3.4.1

quality of service

QoS

a set of qualities related to the collective behaviour of one or more objects

NOTE This definition was drawn from ISO/IEC/DIS 10746-2.1.

3.5 QoS Basic Framework terms

NOTE The terms in this subclause are drawn from ISO/IEC/JTC 1/SC 21 N 9309.

3.5.1

policy control function

PCF

the function that determines policy that is to apply to the operation of the subsystem

NOTE The PCF determines the constraints under which all other decisions of the subsystem are made. Any action is performed to control the remaining operation of the subsystem.

3.5.2**protocol entity****PE**

the entity responsible for operating the protocol in order to provide the service to the service user and also responsible for operating with its peer protocol-entity, its peer service user, and the inferior service provider

3.5.3**quality control function****QCF**

the function that takes account of QoS requirements in selecting the entities that will participate in communications

NOTE The QCF may represent a point of interaction at which knowledge of QoS may be used to influence the choice and at which the consideration of the choice may affect the treatment of QoS.

3.5.4**QoS alert**

the use of QoS mechanisms to signal to an entity that some limit has been reached or threshold crossed

3.5.5**QoS attribute**

an attribute of a managed object relating to QoS

3.5.6**QoS characteristic**

a quantifiable aspect of QoS, which is defined independently of the means by which it is represented or controlled

3.5.7**QoS context**

QoS information that is retained, interpolated or extrapolated by one or more entities and used in managing QoS

NOTE QoS context is further classified into requirement context and data context.

3.5.8**QoS data**

QoS information other than QoS requirements, e.g. warning, QoS measures, and information used in QoS inquiries

3.5.9**QoS enquiry**

the use of QoS mechanisms to determine properties of the environment relating to QoS in which communications take place

3.5.10**QoS establishment**

the use of QoS mechanisms to create the conditions for some systems activity before that activity occurs, so that a desired set of QoS characteristics is attained

3.5.11**QoS information**

information related to QoS classified into QoS context (when retained in an entity), QoS parameters (when conveyed between entities), QoS requirements (if it expresses requirements for QoS) and QoS data (if it does not express requirements for QoS)

3.5.12**QoS maintenance**

the use of QoS mechanisms to maintain a set of QoS characteristics at required values for some systems activity, while the activity is in progress

3.5.13**QoS management**

any set of activities performed by a system or communications service to support QoS monitoring, control, and administration

3.5.14**QoS management function**

a function specifically intended to meet a user or application requirement for QoS, provided by one or more QoS mechanisms

3.5.15**QoS measure**

one or more observed values relating to a QoS characteristic

3.5.16**QoS mechanism**

a specific mechanism that may use protocol elements, QoS parameters, or QoS context, possibly in conjunction with other QoS mechanisms, in order to support establishment, monitoring, maintenance, control, or enquiry of QoS

3.5.17**QoS monitoring**

the use of QoS measures to estimate the values of a set of QoS characteristics actually achieved for some systems activity

3.5.18**QoS parameter**

QoS information that is conveyed between entities as part of a QoS mechanism

NOTE Parameters are classified into requirement parameters and data parameters. The information conveyed may relate to one or more QoS characteristics.

3.5.19**QoS requirement**

QoS information that expresses part or all of a requirements to manage one or more QoS characteristics, e.g. a maximum value, a target, or a threshold

NOTE When conveyed between entities, a QoS requirement is expressed in terms of QoS parameters.

3.5.20**QoS operating target**

QoS information that represents the target values of a set of QoS characteristics, derived from QoS requirements

3.6 TCNM terms**3.6.1****network management management entity (NM)-ME**

a management service entity or management agent responsible for operating management actions, e.g. state control and report, alarm report, logging, violation report, access control, monitor metrics, test control, scan report, scheduling, resource control, knowledge management, etc., and for operating the (NM)-protocol in order to co-operate with other peer (NM)-subsystem in the sense of system management in OSI management

NOTE The (NM)-ME combines two functions classes that represent both a system-wide and a locally restricted capability for tuning and coordinate the behaviour of the various QoS entities in operation in distributed TCNM subsystems.

3.6.2**network management policy control function (NM)-PCF**

the function that determines the TCNM policy that is to apply to the operation of the TCCN

NOTE The (NM)-PCF determines the constraints under which all other decisions of the (NM)-subsystem are made, and the constraints affects the (N)-PCF in the (N)-subsystem in order to fulfill the QoS requirements imposed on TCCN. Any action is performed to control the remaining operation of the (NM)-subsystem.

3.6.3**network management quality control function****(NM)-QCF**

the function that takes account of QoS requirements in selecting the entities that will participate in the network management

NOTE The (NM)-QCF represents a point of interaction at which knowledge of QoS will be used to influence the choice and at which the consideration of the choice will affect the treatment of QoS.

3.6.4**TCNM-management information base****TCNM-MIB**

a conceptual repository in which common knowledge of the behaviour of the various QoS entities in operation will be used to influence the policy control, the QoS control, the protocol processing and the management agent processing

3.6.5**time-critical communications network****TCCN**

a network of an implementation of a time-critical communications architecture

3.6.6**time-critical network management****TCNM**

network management which supports network management functionality to be identified in this work

NOTE TCNM primarily covers a network management within a TCCN.

4 User requirements for time-critical communications systems**4.1 Introduction**

User requirements for time-critical communications systems (TCCS) can be grouped into these categories: user control, integration issues of openness, timing-related issues, and architecture considerations including topology, management, and sovereignty aspects. These requirements are discussed separately in detail in 4.3 to 4.6.

4.1.1 Summary of user control requirements

User control requirements can be summarized as follows:

- a) differentiation of messages is essential;
- b) user control of error recovery;
- c) user specification of behaviour.

4.1.2 Summary of integration issues of openness

Integration issues of openness can be summarized as follows:

- a) the TCCA shall be defined within the context of OSI;
- b) TCCAs shall support ISO/IEC 9506 functionality in a timely fashion;
- c) the TCCA requires standardized user interfaces.

4.1.3 Summary of timing-related issues

Timing-related issues can be summarized as follows:

- a) agreed probability of message transfer time or transaction completion time is necessary;
- b) Temporal coherence is required and spatial coherence may be required in TCCA, i.e.
 - 1) temporal coherence,
 - 2) time-critical communications transaction,
 - 3) spatial coherence, and
 - 4) synchronization.

4.1.4 Summary of architecture considerations

Architecture considerations can be summarized as follows:

- a) scheduling functions, i.e.
 - 1) differentiation of PDUs,
 - 2) non-time-critical PDUs shall not prejudice the delivery of time-critical PDUs, and
 - 3) static and dynamic scheduling;
- b) dependability, i.e.
 - 1) message transfer time,
 - 2) mechanisms to assist latent failure detection are desirable in TCCSs, and
 - 3) availability;
- c) network management, i.e.
 - 1) membership of TCCS shall be controlled,
 - 2) reconfigurability of the application and the use of the TCCS,
 - 3) off-segment communication, and
 - 4) management and sovereignty;
- d) some protocols implementation aspects, i.e.
 - 1) applications requiring time-critical traffic shall not commit time-critical PDUs to the transmitting stack faster than it or the network or the receiving stack can handle the traffic, and
 - 2) class of conformance to individual requirement level.

4.2 Transaction models

A TCC architecture needs to provides for a number of different communication scenarios. In general the user's overview is perceived from the application; an AE may map directly to the TCC entity or party to the TCC entity because it also has non-TCC-entity elements in it (see Figure 3).

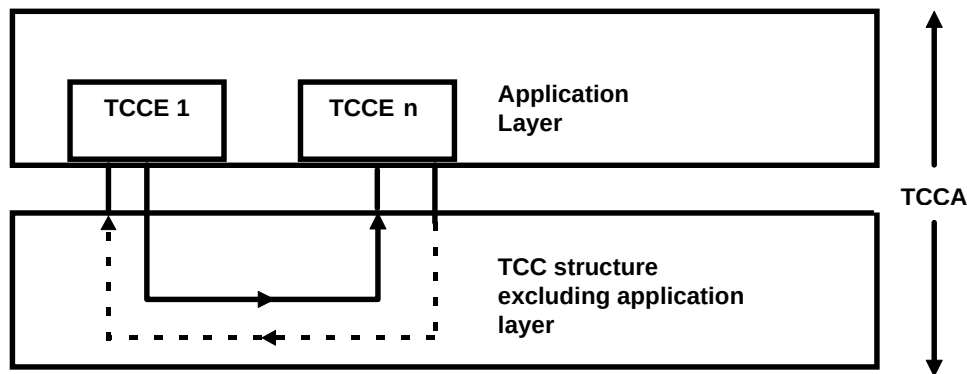


Figure 3 — Relationship of TCCEs and TCCA

A variety of application models have been identified and are referred to as client-server, initiator-responder, producer-consumer, producer-distributor-consumer, etc. The following types of transfers have been identified as essentials for TCC, but the technical implications for TCC systems are not discussed in detail as these will depend on the particular TCC system chosen and its implementation:

- point-to-point, i.e. an exchange from one sender to one receiver;
- multicast, i.e. an exchange from one sender to many (n) receivers which form a known group of TCC entities.

NOTE Where an exchange is from one sender to all receivers without negotiation of the communications context it may be referred to as broadcast.

In applications there will be the following interactions:

- peer-to-peer interaction, where the application which initiates the interaction or requests the service (the initiator) is the sender and there may or not be a requirement for a response (see Figures 4a and 4b);
- multipeer interaction, where the initiator may make one multipoint transfer or n point to transfers and again there may, or may not, be a requirement for responses, which may be confirmations from each member of the group (see Figures 5a, 5b and 5c);
- peer-to-distributing peer is sometimes recognized as a third category, but this can be equated to Figures 4a or 4b and 5a, 5b or 5c depending on what level of confirmation is required (see Figure 6).

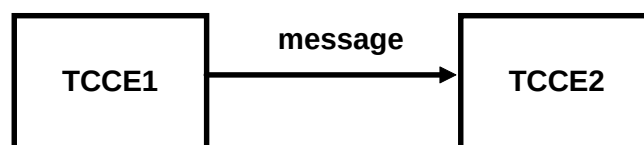


Figure 4a — Peer-to-peer without confirmation

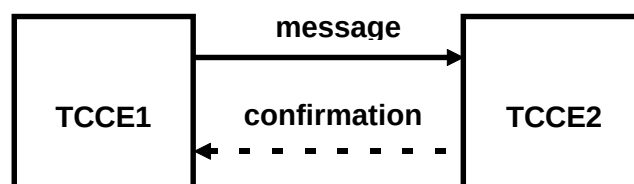


Figure 4b — Peer-to-peer with confirmation

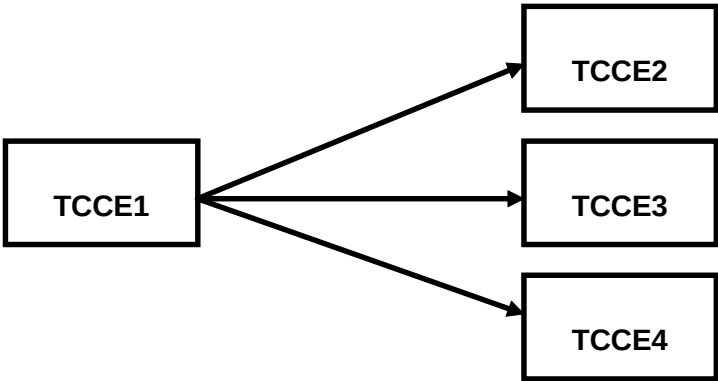


Figure 5a — Multicast of members of group without confirmation

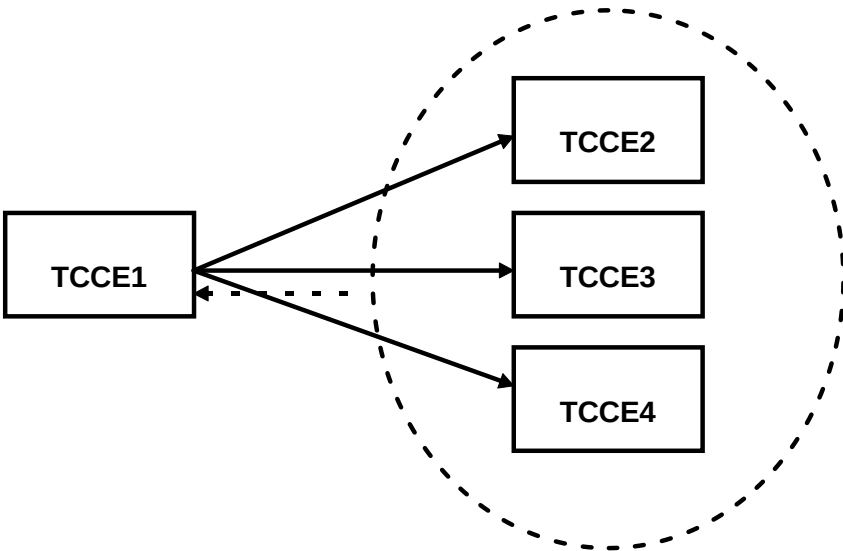


Figure 5b — Multicast to members of a group with confirmation from group of receipt of that message

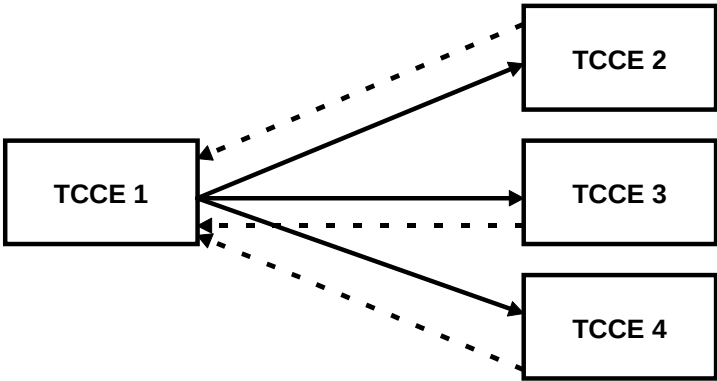


Figure 5c — Multicast to members of a group with individual confirmation to that message transfer from each member

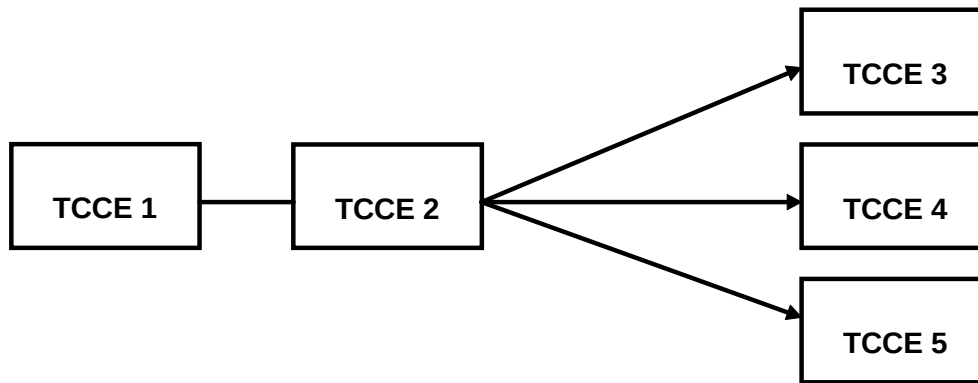


Figure 6 — Peer-to-distributing peer

A TCC system clearly requires point-to-point communication. There should be a facility which allows an application to invoke procedures or request services, or information, or both, on an ad-hoc basis. In many situations a TCC system needs the capability to conduct communications with several applications at the same instant, such as the synchronization of real-time clocks at multiple locations. Apparently that TCC systems require multicast capability for spatial resources and temporal coherence and for efficient use of limited resources, e.g. bandwidth. Finally, there is a requirement to minimize the communications requirements on simple devices, while allowing open access to the most the current data.

Distributed real-time applications are expected to have a varied mix of messages including periodic traffic (e.g. remote data samples), aperiodic regular traffic (e.g. file transfers, user requests), and sporadic traffic (e.g. alarms, reconfiguration requests). Therefore a TCC system has to support both periodic and aperiodic traffic, i.e. both state-driven and event-driven traffic. Since many time-critical applications will be event-driven (i.e. there will be variable loading on the network in terms of traffic, TCC entities, etc.), time-critical traffic has to be able to be sent within prescribed time windows with an acceptable probability of success in all circumstances.

4.3 User control

Some parameters and characteristics which define or contribute to the behaviour of the traffic communication system must be specified by the user. The communication system does not have knowledge regarding

- membership behaviour,
- error recovery, and
- defining the urgency of messages.

4.3.1 Differentiation of messages is essential

4.3.1.1 Summary

The application can differentiate between time-critical and non-time-critical messages. In addition it is necessary for the communications system to distinguish between time-critical and non-time-critical messages and provide appropriate service.

4.3.1.2 Explanation

The differentiation of messages should be dynamically allocated when the application commits the message to the TCC entity. Once the messages have been differentiated the communication system should carry the messages from source to destination without altering their designation.

Differentiation could be done by using attributes attached to the PDUs, and/or multiple (dual) stacks. The former is the most elegant solution but involves changing many existing standards whereas the latter could be introduced more immediately. The coexistence of time-critical and non-time-critical PDUs in a single stack architecture may lead to processing difficulties so multiple stacks may be required in addition to PDU tagging. Other alternative mechanisms may be devised to allow the differentiation of messages in TCC systems. It may be a requirement that time-critical PDUs can pre-empt non-time-critical PDUs.