IEC 61850 Systems and Their Components

Dr. Alexander Apostolov
Questions

• What are we doing?
• Why are we doing it?
• How are we doing it?
Communication in Substations

- Centralized monitoring and control
- With numerical relays (IEDs) substation automation has become more popular and easy to install
- Reduced hardwiring – saving time and effort on commissioning and maintenance
What is IEC 61850?

IEC 61850
14 Parts
>1000 pages (English only !)
10 years of development

REAL SUBSTATION
Different vendors
Interoperability
Easy specification
Working Groups at Work
Working Groups at Work
Working Groups at Work
Working Groups at Work
Fred
Working Groups at Play
Working Groups at Play
# IEC 61850 Standard - Organization

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</tr>
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<td></td>
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</tr>
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<td></td>
<td><strong>Part 10: Conformance Testing</strong></td>
</tr>
<tr>
<td>Type</td>
<td>Name</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>1a</td>
<td>Fast messages – trip</td>
</tr>
<tr>
<td>1b</td>
<td>Fast messages – others</td>
</tr>
<tr>
<td>2</td>
<td>Medium speed messages</td>
</tr>
<tr>
<td>3</td>
<td>Low speed messages</td>
</tr>
<tr>
<td>4</td>
<td>Raw data messages</td>
</tr>
<tr>
<td>5</td>
<td>File transfer functions</td>
</tr>
<tr>
<td>Type</td>
<td>Name</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>6a</td>
<td>Time synchronisation messages station bus</td>
</tr>
<tr>
<td>6b</td>
<td>Time synchronisation messages process bus</td>
</tr>
<tr>
<td>7</td>
<td>Command messages with access control</td>
</tr>
</tbody>
</table>
IEC 61850 - in brief

• Not just another bus system...
• Goes far beyond almost all other communication standards
• It extends the way automation devices “work together”
• Defines WHAT to communicate and HOW to communicate
• Everything has a name
• Configuration language for devices and substations
IEC 61850 - in brief

• Selects communication protocols
• Applicable in substations and many other domains
  – Wind power
  – Distributed Energy Resources
  – Hydro
IEC 61850 - Scope

WG10: Functional Architecture and General Requirements

SUBSTATION LEVEL FUNCTIONS

- Bay Unit
  - Control
  - Metering
  - Disturbance recorder
  - Misc. Functions

- Protection
  - Disturbance recorder

Remote control (NCC)
Technical services

Level 2

Level 1

Level 0

Instrumental transformers
TC38

Switchgear and transformer
TC14, TC17

Instrumental transformers
TC38

Switchgear and transformer
TC14, TC17

TC57

TC95

TC95

TC14, TC17
• WG11: Communication within and between Unit and Station levels
Process Bus

• WG12: Communication within and between Process and Unit levels
IEC 61850 Related Working Groups

- **Working Group 15**: Data and communication security
- **Scope**: Undertake the development of standards for security of the communication protocols defined by the IEC TC 57
IEC 61850 Related Working Groups

• **Working Group 19**: Interoperability within TC 57 in the long term
• **Scope**: Harmonization of IEC 61850 and CIM
Technical Reports IEC 61850-90-x

• A technical report IEC 61850-90-1 that will be published this fall will describe the use cases of applications that require information exchange between substations.

• Examples: line differential protection or distance protection with blocking schemes.
Technical Reports

• A technical report IEC 61850-90-2 that will describe the use of IEC 61850 for applications that require information exchange between substations and control center.
Technical Reports

• IEC 61850-90-3 shall describe the aspects of using IEC 61850 for condition monitoring of power equipment.

• The modeling of the information gathered by condition monitoring devices will be an essential part, but the specification of a mapping for a sensor bus might be included in that work as well.
Technical Reports

• IEC 61850-90-4 Technical report: Network Engineering Guidelines

• Will provide definitions, guidelines, and specifications for the network architecture of IEC 61850 based systems
Technical Reports


• That work has been recognized by the US NIST (National Institute of Standards and Technology) as one of the top priorities for the introduction of Smart Grid.
IEC 61850 Standard

- Uses the strengths of the OSI 7 layer communication model
- Station bus
  - Communication between IED and master stations
  - Data polled by Master from IED (Buffered or un-buffered)
  - Inter IED data exchange through multi-cast GOOSE messages
IEC 61850 Standard - Station Bus Mapping

Mapping to stack

- Application (Objects, Services)
  - GOOSE
  - Sampled values
  - Client - Server communication

Adaptation

Mapping per selected stack

- Long-term definitions
  - Safe-guarding investments

Abstract Interface

Stack Interface

- FAST
  - Changes
  - Communication Technology

Real-time requirements

- MMS
- TCP
- IP

Ethernet Link Layer

Ethernet Physical Layer with Priority tagging

Stack selection following state-of-the-art communication technology
Open Systems Interconnection (OSI) Model

- **Application**
  - Selects appropriate service for application

- **Presentation**
  - Provides code conversion, data reformatting

- **Session**
  - Coordinates interaction between end application process

- **Transport**
  - Provides for end to end data integrity and quality of service

- **Network**
  - Switches and routes information

- **Data Link**
  - Transfers unit of information to other end of physical link

- **Physical**
  - Transmits bit stream to medium
OSI Stack

PCI = Protocol Control Inform.
PDU = Protocol Data Unit
H = Header
T = Trailer

Frames (Ethernet, token ring, etc)

PCI = Protocol Control Inform.
PDU = Protocol Data Unit
H = Header
T = Trailer
Communications Process

Peer-to-peer dialog
Requirements of New Standard

• The goal of the IEC 61850 standard is to ensure:

  **Interoperability**: The ability for IED’s from one or several manufacturer to exchange information and use the information for the their own functions.
Requirements of New Standard

• **Free Configuration:** The support of different philosophies and ability for free allocation of functions, i.e. it will work equally well for centralized (RTU like) or decentralized (SCS like) systems.

• **Long Term Stability:** The standard shall be future proof, i.e. it must be able to follow the progress in communication technology as well as evolving system requirements.
Interoperability

• Ability of two or more IEDs from the same vendor, or from different vendors, to exchange information and use that information for correct execution of specified functions

- Request
- Response
- Event

Has a DATA MODEL model that can be accessed

The WHAT to exchange (IEC 61850-7-3 & 4)

The HOW to exchange (IEC 61850-7-2)
Interfaces in IEC 61850 Systems

- Station Level: IED Protection, Control, Measurements, Recording
- Bay Level: IED Protection, Control, Measurements, Recording
- Process Level: Interfaces IF 4, 5, IF 7, 10, IF 1, 6, IF 2
IEC 61850 Standard

• Process bus
  – Communication between plant equipment and IEDs (switchgear, Instrument transformers)
  – Exchange of sampled values
• Bus separation is becoming less distinct
Free Communications Configuration

Substation Computer

Station Level

Station Bus

IED
Protection Measurements
Control Recording

Bay Level

Process Bus

IED
Protection Measurements
Control Recording

Process Bus

Process Level
Free Communications Configuration
Virtualization

IEC 61850 7-x

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Attr. Type</th>
<th>Explanation</th>
<th>T</th>
<th>M/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNName</td>
<td></td>
<td>Shall be inherited from Logical-Node Class (see IEC 61850-7-2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Logical Node Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loc</td>
<td>SPS</td>
<td>Local operation (local means without substation automation communication, hardwired direct control)</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>EEHealth</td>
<td>INS</td>
<td>External equipment health</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>EEName</td>
<td>DPL</td>
<td>External equipment name plate</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>OpCnt</td>
<td>INS</td>
<td>Operation counter</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pos</td>
<td>DPC</td>
<td>Switch position</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>BlkOpn</td>
<td>SPC</td>
<td>Block opening</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>BlkCls</td>
<td>SPC</td>
<td>Block closing</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>ChaMotEna</td>
<td>SPC</td>
<td>Charger motor enabled</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Metered Values</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SumSWARs</td>
<td>BCR</td>
<td>Sum of Switched Amperes, resettable</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Status Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBOpCap</td>
<td>INS</td>
<td>Circuit breaker operating capability</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>POWCap</td>
<td>INS</td>
<td>Point On Wave switching capability</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>MaxOpCap</td>
<td>INS</td>
<td>Circuit breaker operating capability when fully charged</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>
Virtualization

IEC 61850 7-x

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Attr. Type</th>
<th>Explanation</th>
<th>T</th>
<th>M/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNName</td>
<td></td>
<td>Shall be inherited from Logical-Node Class (see IEC 61850-7-2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Data**

- **Common Logical Node Information**
  - LN shall inherit all Mandatory Data from Common Logical Node Class

- **OpOnRs**
  - INC: Resetable operation counter

**Status Information**

- **St**: Start
  - M
- **Op**: Operate
  - T
- **TmASt**: CSD: Active curve characteristic

**Settings**

- **TmACrv**: CURVE: Operating Curve Type
- **StrVal**: ASG: Start Value
- **TmMulti**: ASG: Time Dial Multiplier
- **MinOpTmins**: ING: Minimum Operate Time
- **MaxOpTmins**: ING: Maximum Operate Time
- **OpDiTmins**: ING: Operate Delay Time
- **TypRsCrv**: ING: Type of Reset Curve
- **RstDiTmins**: ING: Reset Delay Time
- **DirMod**: ING: Directional Mode
Distance Protection Model

Distance Protection IED

- XCBR1
- PTRC1
- TVTR1
- TCTR1
- PDIS1
- PDIS2
- PDIS3
- PSCH1
Distance Protection Model

Distance Protection IED

IOU
XCBR1

MU
TVTR1
TCTR1

PTRC1
PSCH1
PDIS1
PDIS2
PDIS3
Distance Protection Model

![Diagram of Distance Protection Model]
Modeling Approach

- Functional Decomposition
  - Used to understand the logical relationships between components of a distributed function and is presented in terms of logical nodes that describe the functions, sub-functions and functional interfaces

- Data Flow
  - Used to understand the communication interfaces that must support the exchange of information between distributed functional components and the functional performance requirements
Modeling Approach

• Information Modeling
  – Used to define the abstract syntax and semantics of the information exchanged and is presented in terms of data object classes and types, attributes, abstract object methods (services) and their relationships.
Modeling Approach

- Object oriented communications organize the data by function to simplify distributed applications
- Standardized object models allow for application interoperability
- Self-description and Meta-Data allows for online validation
- Focus is shifting from data acquisition to Data Management
## Data Model

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
<th>Term</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Cyc</td>
<td>Cycle</td>
<td>Gri</td>
<td>Grid</td>
</tr>
<tr>
<td>Dea</td>
<td>Dead</td>
<td>H</td>
<td>Harmonics (phase related)</td>
</tr>
<tr>
<td>Den</td>
<td>Density</td>
<td>H₂</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Det</td>
<td>Detected</td>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>DExt</td>
<td>De-excitation</td>
<td>Ha</td>
<td>Harmonics (non phase related)</td>
</tr>
<tr>
<td>Diag</td>
<td>Diagnostics</td>
<td>Hi</td>
<td>High, highest</td>
</tr>
<tr>
<td>Dif</td>
<td>Differential, difference</td>
<td>HP</td>
<td>Hot point</td>
</tr>
<tr>
<td>Dir</td>
<td>Direction</td>
<td>Hz</td>
<td>Frequency</td>
</tr>
<tr>
<td>Dis</td>
<td>Distance</td>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
</tr>
<tr>
<td>DI</td>
<td>Delay</td>
<td>Imb</td>
<td>Imbalance</td>
</tr>
<tr>
<td>Dlt</td>
<td>Delete</td>
<td>Imp</td>
<td>Impedance non phase related</td>
</tr>
<tr>
<td>Dmd</td>
<td>Demand</td>
<td>In</td>
<td>Input</td>
</tr>
<tr>
<td>Dn</td>
<td>Down</td>
<td>Ina</td>
<td>Inactivity</td>
</tr>
<tr>
<td>DPCS0</td>
<td>Double point controllable status output</td>
<td>Incr</td>
<td>Increment</td>
</tr>
<tr>
<td>DQ0</td>
<td>Direct, Quadrature, and zero axis quantities</td>
<td>Ind</td>
<td>Indication</td>
</tr>
<tr>
<td>Drag</td>
<td>Drag hand</td>
<td>Inh</td>
<td>Inhibit</td>
</tr>
<tr>
<td>Drv</td>
<td>Drive</td>
<td>Ins</td>
<td>Insulation</td>
</tr>
<tr>
<td>DS</td>
<td>Device State</td>
<td>Int</td>
<td>Integer</td>
</tr>
<tr>
<td>Dsch</td>
<td>Discharge</td>
<td>ISCSO</td>
<td>Integer status controllable status output</td>
</tr>
<tr>
<td>Dur</td>
<td>Duration</td>
<td>km</td>
<td>Kilometre</td>
</tr>
<tr>
<td>EC</td>
<td>Earth Coil</td>
<td>L</td>
<td>Lower</td>
</tr>
<tr>
<td>EE</td>
<td>External Equipment</td>
<td>LD</td>
<td>Logical Device</td>
</tr>
</tbody>
</table>
## Semantics

<table>
<thead>
<tr>
<th>Data Name</th>
<th>Semantics</th>
</tr>
</thead>
</table>
| PolQty    | This Data indicates the reference quantity used to determine fault direction.  
  |  
  | Polarizing Quantity | Value |
  | None | 1 |
  | Zero sequence current | 2 |
  | Zero sequence voltage | 3 |
  | Negative sequence voltage | 4 |
  | Phase to Phase Voltages (Cross Polarising) | 5 |
  | Phase to Ground Voltages | 6 |
| PoRch     | Polar Reach is the diameter of the Mho diagram, see PctRch. |
| Pos       | This Data is accessed when performing a switch command or to verify the switch status or position. When this Data is also used for a hand-operated switch, the (optional) CtlVal attribute in IEC 61850-7-3 does not exist. |
| PosA      | This Data shall be used for switching, where single phase A may be operated separately. |
| PosB      | This Data shall be used for switching, where single phase B may be operated separately. |
| PosC      | This Data shall be used for switching, where single phase C may be operated separately. |
| POWCap    | Point On Wave switching capability.  
  |  
  | POW Switching Capability | Value |
  | None | 1 |
  | Close | 2 |
  | Open | 3 |
  | Close and Open | 4 |
| PPV       | Phase to phase voltages. |
| PPVVal    | Undervoltage level for WEI conditions for a phase-phase measurement. |
| Pres      | Pressure in a specific volume. |
| PresAlm   | Pressure alarm because of an abnormal condition (FALSE = Normal, TRUE = alert) |
## Logical Nodes in IEC 61850

- Logical Nodes – 92 LN Classes

<table>
<thead>
<tr>
<th>Logical node groups</th>
<th>Number of logical nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>System logical nodes</td>
<td>3</td>
</tr>
<tr>
<td>Protection functions</td>
<td>28</td>
</tr>
<tr>
<td>Protection related functions</td>
<td>10</td>
</tr>
<tr>
<td>Supervisory control</td>
<td>5</td>
</tr>
<tr>
<td>Generic references</td>
<td>3</td>
</tr>
<tr>
<td>Interfacing and archiving</td>
<td>4</td>
</tr>
<tr>
<td>Automatic control</td>
<td>4</td>
</tr>
<tr>
<td>Metering and measurement</td>
<td>8</td>
</tr>
<tr>
<td>Sensors and monitoring</td>
<td>4</td>
</tr>
<tr>
<td>Switchgear</td>
<td>2</td>
</tr>
<tr>
<td>Instrument transformer</td>
<td>2</td>
</tr>
<tr>
<td>Power transformer</td>
<td>4</td>
</tr>
<tr>
<td>Further power system equipment</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total number of logical nodes</strong></td>
<td><strong>92</strong></td>
</tr>
</tbody>
</table>

- **PDIR**: Directional element
- **PHAR**: Harmonic restraint
- **PSCH**: Protection Scheme
- **PTEF**: Transient Earth Fault
- **PZSU**: Zero speed or underspeed
- **PDIS**: Distance protection
- **PVPH**: Volts per Hz relay
- **PTUV**: Undervoltage
- **PDOP**: Directional over power
- **MMXU**: Measuring (Measurand unit)
- **MMTR**: Metering
- **MSQI**: Sequence and Imbalance
- **MHAI**: Harmonics and Inter-harmonics
- **MDIF**: Differential Measurements
- **XCBR**: Circuit Breaker
- **XSWI**: Circuit Switch

"IEC61850-7-1 Standard"
### Logical Node Groups

- Logical Groupings – 13 different groups

<table>
<thead>
<tr>
<th>Group Indicator</th>
<th>Logical node groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Automatic Control</td>
</tr>
<tr>
<td>C</td>
<td>Supervisory control</td>
</tr>
<tr>
<td>G</td>
<td>Generic Function References</td>
</tr>
<tr>
<td>I</td>
<td>Interfacing and Archiving</td>
</tr>
<tr>
<td>L</td>
<td>System Logical Nodes</td>
</tr>
<tr>
<td>M</td>
<td>Metering and Measurement</td>
</tr>
<tr>
<td>P</td>
<td>Protection Functions</td>
</tr>
<tr>
<td>R</td>
<td>Protection Related Functions</td>
</tr>
<tr>
<td>S &lt;sup&gt;a)&lt;/sup&gt;</td>
<td>Sensors, Monitoring</td>
</tr>
<tr>
<td>T &lt;sup&gt;a)&lt;/sup&gt;</td>
<td>Instrument Transformer</td>
</tr>
<tr>
<td>X &lt;sup&gt;a)&lt;/sup&gt;</td>
<td>Switchgear</td>
</tr>
<tr>
<td>Y &lt;sup&gt;a)&lt;/sup&gt;</td>
<td>Power Transformer and Related Functions</td>
</tr>
<tr>
<td>Z &lt;sup&gt;a)&lt;/sup&gt;</td>
<td>Further (power system) Equipment</td>
</tr>
</tbody>
</table>

<sup>a)</sup> LNs of this group exist in dedicated IEDs if a process bus is used. Without a process bus, LNs of this group are the I/Os in the hardwired IED one level higher (for example in a bay unit) representing the external device by its inputs and outputs (process image – see Figure B.5 for example).
Data Groups in IEC 61850

Logical node

Logical node information

Common logical node information
information independent from the dedicated function represented by the LN, e.g., mode, health, name plate, etc.

Status information
information representing either the status of the process or of the function allocated to the LN, e.g., switch type, switch operating capability, etc.

Settings
information needed for the function of a logical node, e.g., first, second, and third reclose time, close pulse time, and reclaim time of an autoreclosing function

Measured values
are analogue data measured from the process or calculated in the functions like currents, voltages, power, etc., e.g., total active power, total reactive power, frequency, net real energy since last reset, etc.

Controls
are data which are changed by commands like switchgear state (ON/OFF), tap changer position or resetable counters, e.g., position, block opening, etc.
Data Attributes in IEC 61850

IEC 61850-7-1 Standard

Logical node

XCBR

Data

Control value “ctlVal”
Operate time
Originator
Control number
Status value “stVal”
Quality
Time stamp
Substit. enable
Substit. value
Pulse configuration
Control model
SBO timeout
SBO class
...

Pos

BlkOpn

Data-Attributes

Controllable

control

status value

status

substitution

configuration, description, and extension
IEC 61850 Class Model

Class Model of IEC 61850-7 (Example)

Instances (Examples)

{Aggregation determined by 7-4 table-references }

{Values and Types are determined by Common Data Classes}

Logical Node Classes defined in 7-4

Data Classes defined in 7-4

Common Data Classes defined in 7-3

myXCBR1: XCBR

pos1: POS

stVal: DATA-ATTRIBUTE

abc: SERVER

xyz: LOGICAL-DEVICE
Self-describing Data

• A client can discover the device server’s capabilities
• Comparable to the services of a web browser
• Used initially when defining the system configuration or during tuning/maintenance of the system
Information Flow - Services

- Set, Operate, … <values>
- Report <values>
- Get, GetDef, …
- multicast <values>
Basic Reference Model - Services

Diagram showing the relationship between application layers, specific communication service interfaces, and generic models.

- Application
  - SCSM 1
    - AL 1
  - SCSM 2
    - AL 2
  - SCSM n
    - AL n

Specific communication service mapping and abstract communication service interface.

IEC 1380/03
Logical Devices as Proxy Servers
Mapping Example

Single Line Diagram

Physical Device Bay Controller

- GGIO: General Input / Output
- XCBR: Circuit Breaker
- TCTR: Current Transformer
- TVTR: Voltage Transformer
- ATCC: Tap Changer Controller
- GAPC: Automatic Process Control
- XARC: Monitoring for Arcs
- PDIS: Distance Projection
- RFLO: Fault Locator
- RDRE: Disturbance Recorder
- MMXU: Measurement Unit

Example for some current related information
Mapping to MMS

IEC 61850-7-2

IEC 61850-7-3

IEC 61850-7-4

Information Models

Common DATA Classes

DATA-SET

Control Blocks
(BRCB, URCB, GoCB, LCB)

LOG

DATA

LOGICAL NODE

LOGICAL DEVICE

MMS Named VariableList

MMS Named Variable

Control Blocks

Control Block Attributes

Control Block Behavior

GetDataValues -> Read
SetDataValues -> Write

Domain

MMS message

xyz = MMS object

IEC 61850-8-1
IEC61850 Key Benefits

• Speed: 100 Mbps instead of few 10 kbps
  – More data for better operation & maintenance

• Peer-to-peer: No extra hardware
  – Design of innovative automation schemes, late tuning

• Conditional report instead of polling
  – Optimal performances

• IP (Internet Protocol) routing
  – Capability to extend the system outside of the substation
IEC61850 Key Benefits

• Client-server: Instead of master-slave
  – Flexible designs easy to upgrade
• Pre-defined names: Single vocabulary between users
  – Easier engineering between teams
• XML references: Formal interfaces
  – Consistency between engineering tools
• IEC 61850 is independent of short term benefits: focuses on the “long living application objects”
IEC61850 Key Benefits

• Independent of current product; stable over several product cycles (long term stability)
• Independent of operating systems and programming languages
• Independent of middleware
• Independent of communication systems
• Independent of vendor (multi-vendor support)