New Node Integration in TTP/A Networks

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Abstract

The industry calls for fieldbus architectures that allow transducer nodes to be connected into a network in a true "plug and play" fashion.

A plug and play configuration consists of at least three tasks: to identify the new nodes, to obtain the documentation, and to download the configuration. This paper deals with node identification and configuration programming for the TTP/A fieldbus.

We present a method for identification and configuration of new nodes that is suitable for master-slave fieldbus networks with deterministic timing behavior. The method integrates well with the TTP/A protocol and is implementable in standard TTP/A slave and master nodes. Even though configuration of new components is normally not time critical, our method inherits a deterministic timing behavior from the TTP/A protocol and can be used in parallel with real-time traffic for hot plug and play of new nodes.

Keywords: TTP/A, Plug and Play, Smart Sensor, In-System Configuration, Fieldbus, Embedded Systems.

1 Introduction

The installation and configuration of a new network is a difficult task. The system integrator must identify many different nodes, access their specification and integrate them into the network according to their specification. Currently these steps are often performed *manually*, with high human resource costs and a fair probability of misconfiguration due to human errors [1].

With large data acquisition systems, there is a need for self-identification of nodes. This means that a node can describe itself to the network, thus facilitating an automatic system configuration. This feature provides substantial savings in the labor required to identify new nodes, record serial numbers, calibration factors and data for transducers and reduces the chance of error.

Plug and Play functionality is already integrated in the personal computer world. In the fieldbus world, the many existing protocol standards complicate the introduction of consistent and vendor-spanning plug and play systems. There exist software tools working on Profibus, Ethernet [2], CAN and the Foundation Fieldbus [3]. Standard configuration interfaces are presented by the IEEE P1451 [4] standard and the Common Object Request Broker Architecture (CORBA) [5].

The smart transducer interface standard IEEE P1451 supports self-identification via a memory chip physically attached to the node. This chip stores information such as manufacturer name, identification number, device type, and calibration data. This information is called the transducer electronic data sheet (TEDS) [6].

CORBA offers object services (Naming/Trading, Events, etc.) that provide important features to plug and play components. CORBA can be used to implement a consistent interface to whole fieldbus clusters [7] but most smart transducer node resources, especially for low-cost solutions in mass markets, would not suffice for the implementation of CORBA interfaces.

A plug and play configuration consists of at least three tasks: to identify the new nodes, to obtain the documentation, and to download the configuration. The second task is assigned to configuration tools that access electronic documentation from databases at a higher level than the fieldbus level. This paper deals with node identification and configuration programming that rely on the fieldbus network level.

While new node identification is trivial in many networks it is a difficult task in networks where deterministic behavior is achieved by master-slave addressing. In case of new nodes, the master doesn't have knowledge of the identifiers of new nodes, because addressing of such is not supported. If the new nodes are connected one by one, a special command for addressing any new node can be used for assigning a node identifier (baptizing). However when a number of new nodes are expected, a different addressing among the new nodes has to be implemented. The linear search through the name space is often impossible because of the high number of possible nodes (e. g. in the TTP/A protocol nodes own an eight byte identifier, yielding 2^{64} iterations!).

For the TTP/A network we searched for (and found) a method that integrates well with the existing TTP/A communication features at an expense of about 64 iterations.

The rest of the paper is organized as follows: Section 2 gives an overview on the TTP/A protocol and describes especially the mechanism that is used for the node identification function. Section 3 describes a method for automatic node identification and address configuration called *baptizing*. Section 4 examines requirements for transducer nodes supporting plug and play. Section 5 discusses the application scope of the presented approach, suggests some optimizations and gives some implementation experiences. Finally, the basic ideas of this paper are summarized in Section 6.

2 The TTP/A Protocol

Basic Principles

TTP/A is a time-triggered master-slave communication protocol for fieldbus applications that uses a time division multiple access (TDMA) bus arbitration scheme [8].

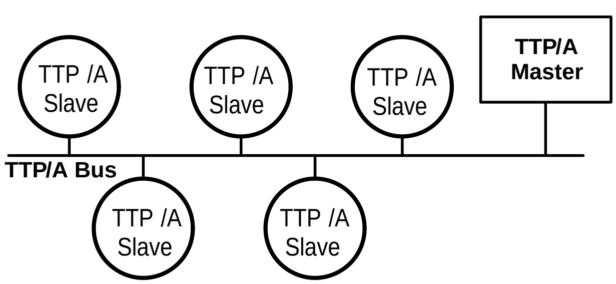


Figure 1: TTP/A Cluster

It is possible to address up to 254 nodes on a bus. One single node is the active master. This master provides the time base for the slave nodes. The communication is organized into rounds. Bus access conflicts are avoided by a strictly TDMA schedule for each round. A round consists of several slots. A slot is a unit for transmission of one byte of data. Data bytes are transmitted in a standard UART format. Each communication round is started by the master with a so-called fireworks byte. The fireworks byte defines the type of round.

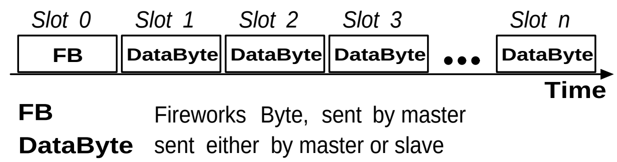


Figure 2: A TTP/A Multipartner Round

A multipartner round (see Figure 2) consists of a configuration dependent number of slots and an assigned sender node for each slot. The configuration of a round is defined in the RODL (ROund Descriptor List). The RODL defines which node transmits in a certain slot, the semantics of each individual slot, and the receiving nodes of a slot. RODLs must be configured in the slave nodes prior to the execution of the corresponding multipartner round.

Master-Slave Rounds

A master-slave round establishes a connection between the master and a slave for reading/writing monitoring or configuration data, e. g. the RODL information. The action and the memory addressing is encoded in three parameter bytes of a master-slave round. In a further part the addressed data bytes are transmitted between master and slave.

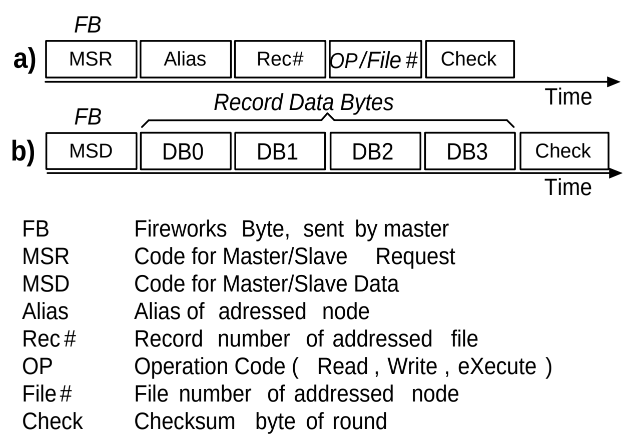


Figure 3: TTP/A Master-Slave Round

Figure 3 depicts the fixed layout of a master-slave round. A master-slave round consists of two parts. In the addressing part (Figure 3 a)) the action and the memory addressing is encoded in three parameter bytes.

In a further part (Figure 3 b)) the addressed data bytes are transmitted between master and slave. The fireworks byte (MSD) is always sent by the master, while the data bytes are either sent by master or slave depending on the action defined in the addressing part.

The last byte of each round contains a checksum byte that protects the communication from bus failures. Master-slave rounds have idempotent semantics, thus it is possible to repeat the action in case of communication failures.

Thus a master-slave round has a fixed layout. The address scheme is derived from the Interface File System that is explained later in this Section.

Figure 4: Recommended TTP/A Schedule

At startup the master uses master-slave (MS) rounds for determining the types of the connected nodes and configuring them. The multipartner (MP) round is intended to establish a periodical, predictable and efficient real-time communication. To support a diagnosis and maintenance access concurrent to the real-time traffic it is recommended to schedule multipartner rounds and master-slave rounds interleaved (see Figure 4).

The Interface File System

For unique addressing of the slave's internals all relevant data of a TTP/A node like round definitions, application specific parameters and I/O properties are organized into a structure called Interface File System (IFS) [9]. The IFS is structured in a record-oriented format. Each record is addressable separately by master-slave rounds.

The Interface File System was introduced for two reasons:

- Provide a consistent view of the transducer properties.
- Decouple subsystems from the point of view of temporal control.

All nodes contain several files that can be accessed over the TTP/A protocol in a unified manner. The minimal set-up for a smart transducer is:

Round Descriptor List (RODL): Each node contains at least one and up to six RODLs that contain TDMA schedules for the TTP/A multipartner rounds.

TTP/A Configuration File: This file contains at least an 8 bit alias which is the slave's name within its cluster.

Documentation File: This file consists of the node's unique identifier. This value is assigned invariably to each node. The number identifies the node's type while the serial number distinguishes nodes of equal type. Optionally this documentation file contains the ASCII text of an uniform resource locator (URL) pointing to a file containing the node's data sheet. Documentation files are read-only from the master's viewpoint.

To support ultra-low-cost implementations of TTP/A slave nodes, it is also possible to omit the implementation of the file system and hard-code the TDMA schedule for the TTP/A multipartner rounds. Such a node would not respond to any master-slave round and does not support configurability. It is possible to build heterogeneous networks with ultra-lost-cost nodes and configurable nodes together but this might have an negative effect for the system overview because the maintenance program is "blind" on the ultra-low-cost nodes.

3 Baptize Algorithm

The baptize mechanism performs a *binary search* on all node identifiers.

Binary Search

The binary search is done by the master. The identification of a new node takes 64 iterations of the algorithm depicted in Figure 5. The master has to keep three 64 bit integer variables, *lo*, *hi* and the comparison identifier *ci*. The values of *lo* and *hi* are only needed internally for the calculation of new *ci* values.

The variables *lo* and *hi* are initialized to the minimum and maximum value of the expected identifiers (*lo:=0x00000000 00000000, hi:=0xFFFFFFFF FFFFFFFF*). During the iterations the values of *lo* and *hi* move towards each other until *lo* equals *hi*. Then, the identifier of a node is found and the master assigns an alias (different to 0xFF) to this node. The assigning of the new alias is supported by a particular *Baptize Operation* described later.

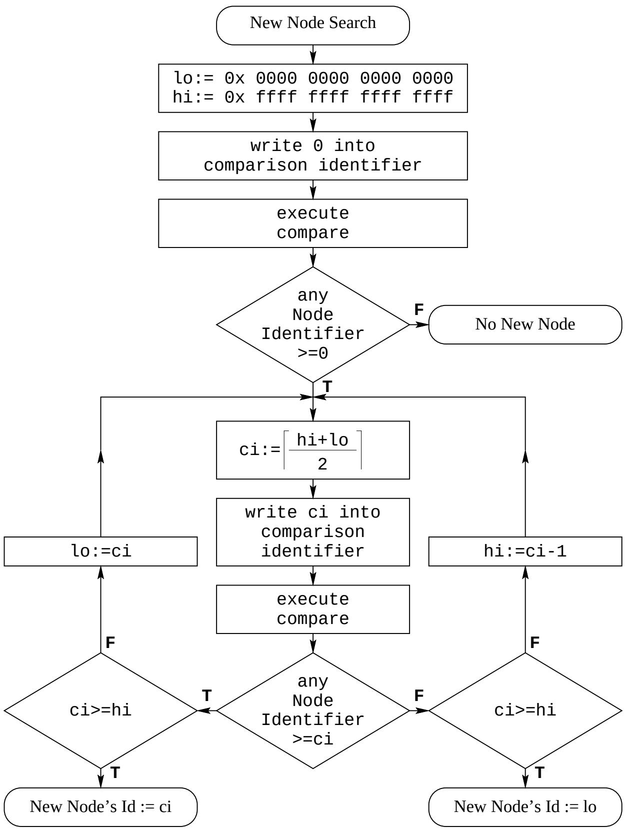


Figure 5: New Node Identification Algorithm

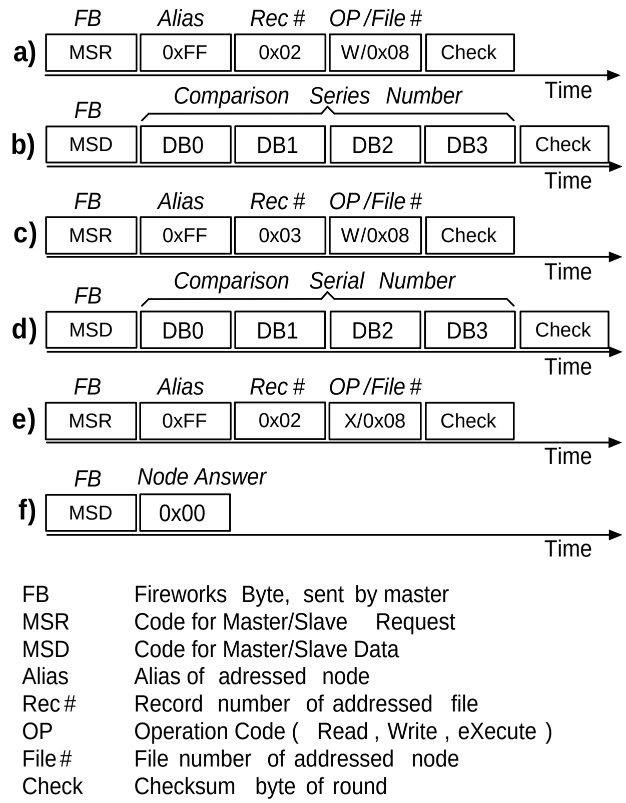


Figure 6: Identifier Comparison

Identifier Comparison

The master performs *identifier comparisons* as follows:

- First, the master sets a lower limit of a node identifier in the nodes to be baptized. The memory for this lower limit is located in the slave node's IFS described as the *comparison series number* and the *comparison serial number*. Henceforth the combination of this value will be called *comparison identifier*.

  The initial value for the comparison identifier is (0x00000000,0x000000). Figure 6 a)-d) depicts the bus interactions for setting a comparison identifier with a master-slave round. The master-slave round normally communicates only between the master and a single slave, but in this case there are several slaves addressed, because all unbaptized slaves have the node alias 0xFF.

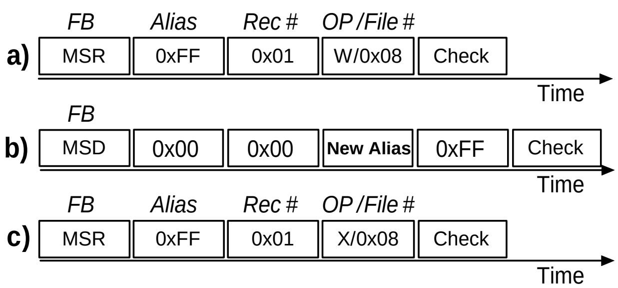
- Then the master broadcasts an execute command on the comparison series number file (Figure 6 e)). The special action assigned with an execute command on that file/record is the comparison of the slave's own hard-coded identifier to the comparison identifier written before.

- The fireworks byte of the second part of the master-slave round initiates a round where all nodes with alias 0xFF whose hard-coded identifier is higher or equal than the comparison identifier write a data frame with content 0x00 in the first slot (see Figure 6 f)). If there are no nodes fulfilling this condition, there are no further bytes sent in this round.

The TDMA rounds for the comparison depicted in Figure 6 a)-f) may be interleaved by other multipartner rounds (The blocks a)-b), c)-d), and e)-f) may even be interleaved by other master-slave rounds. Thus it is possible to perform identifier comparisons concurrently with real-time operation of the already integrated nodes.

Baptize Operation

When the Series and Serial number of an unbaptized node are known, either derived from the above presented binary search algorithm or entered on a console by a system manager, the master has to change the node alias of the particular node from unbaptized (0xFF) to its intended alias. Because there may multiple unbaptized nodes in the network, a simple master-slave write access will not success in this task, because the addressing with the alias 0xFF will not be unique. Therefore the nodes have to support a mechanism to overwrite only the alias of the node with a special Series and Serial number.



FB	Fireworks Byte, sent by master
MSR	Code for Master/Slave Request
MSD	Code for Master/Slave Data
Alias	Alias of adressed node
Rec #	Record number of addressed file
OP	Operation Code (Read , Write , eXecute)
File #	File number of addressed node
Check	Checksum byte of round

Figure 7: Baptize Operation

The Baptize operation includes the setting of the Comparison Identifier to the Series and Serial number of the node desired to baptize. This is done by two master slave write rounds (Figure 6 a)-b) and 6 c)-d)). Afterwards the desired new alias is written into the *node alias buffer* which resides in the same record as the node alias (See Section 4: the node alias buffer occupies byte 0x02, the node alias occupies byte 0x03) by a normal master-slave write round (Figure 7 a)-b)). Because a master-slave write round accesses always a whole record, all four bytes are overwritten. As depicted in Figure 7 a) the values to be written are 0x00, 0x00, the desired node alias, and 0xFF.

For setting the alias in the desired node we use an execute command on file 0x08, record 0x01 (Figure 7 c)). This command causes the nodes whose comparison identifier is equal to its hard-coded node identifier to copy the value of the new alias to the alias byte. Thus the node responds to future requests on its new alias. It is the task of the master to keep an account of assigned aliases.

4 Requirements For Baptizing

There are some few requirements for nodes to support an in-system plug and play functionality (There are no extra requirements for all other nodes except that they may not use the node alias 0xFF):

Protocol Requirements

The TTP/A protocol includes a generic smart transducer interface with an interface file system (IFS) that offers versatile possibilities for configuration management. The presented approach does not require modifications on the protocol.

Slave Node Requirements

Plug-and-Play configurable nodes must support master-slave rounds with the read, write and execute command and contain at least the following entries in its file system:

- Documentation File No. 0x3E (read only) containing
  - Record 0x01: Most significant 4 bytes of node identifier
  - Record 0x02: Least significant 4 bytes of node identifier
- Configuration File No. 0x08 (all records read- and writeable) containing
  - Record 0x01: Byte 0x00 and 0x01 are reserved, Byte 0x02 contains a node alias buffer, Byte 0x03 contains the node alias, must be initialized to 0xFF
  - Record 0x02: Comparison Series Number, this record has assigned an execute function
  - Record 0x03: Comparison Serial Number

Experiences from TTP/A slave protocol implementations on various platforms [10, 11, 12] have shown that the hardware requirements are moderate. The minimal TTP/A slave protocol needs about 1.5 kB of program memory, 64 bytes RAM and 1 MIPS processing speed (for networks up to 19200 Bit/sec). Because the demanding parts of the node identification algorithm are executed in the master node, the slave nodes stay slim and need just about 10 more bytes of RAM memory for the comparison identifier, the node alias buffer and some state flags.

Task	Not Optimized	Optimized
Initial baptizing (10 nodes)	23,77 sec	15,97 sec
Writing configuration (10 nodes)	0,244 sec	0,244 sec
Identifying a new node during operation	5,92 sec	5,14 sec
Writing configuration for 1 node during operation	0,079 sec	0,079 sec

Table 1: Durations for Node Identification and Configuration

Master Node Requirements

The hardware requirements for a typical TTP/A master are between 3.5 kB and 8 kB programm memory and about 1 kB RAM additional to the RAM used by the files. The filesystem must at least contain one RODL ($\approx$ 40 bytes), three special RODLs (12 bytes), documentation file (12 bytes) and the configuration file (16 bytes). The implementation of the baptize mechanism incorporates functions for the binary search, baptize algorithm and communication structures for accessing a configuration database. These functions can easily be supported with the typical TTP/A master hardware.

5 Discussion

The complexity order of the presented approach has the same magnitude as the best possible. However the implementation of the communication between master and slaves has not been optimized for speed. The breakdown of the method in master-slave rounds costs some time, but is justified by:

- The configuration phase is normally not time critical.
- The presented method integrates well with the TTP/A protocol without changes to the specification.
- Interleaving multipartner and master-slave rounds enable *hot plug and play* during real-time system operation.

The presented algorithm can be accelerated by omitting the rewriting of comparison serial or series numbers that did not change from one iteration to the next. For a comparison we defined a test network running at 19200 Bit/sec containing 10 transducer nodes and one master.

Table 1 shows the calculated durations for different tasks. For the initial baptizing and configuration writing we assumed that all 10 nodes are new and need to be detected, and the full bandwidth is available for detection. For node detecting and configuring during operation we assumed, that each of the 10 integrated nodes periodically sends two bytes of data. Between this communication rounds the parts of a master-slave round are scheduled. The third column in the table depicts the improvements achieved by the acceleration of the baptize algorithm as proposed above.

Another application of the approach is automatic new node detection. Figure 5 shows that the algorithm terminates in the first iteration if no new node is present. This property can be used to build a system with automatic new node detection where the master polls periodically for new slaves during real-time operation.

Furthermore the algorithm can be used for repairing a cluster where several nodes have assigned the same alias. While such an erroneous configuration is not solvable in a standard TTP/A system, the application of the presented algorithm on such a cluster can reassign different aliases if the concerned nodes support identifier comparison and baptize operations.

6 Conclusion

We presented a method for new node identification and configuration that is suitable for master-slave fieldbus networks with deterministic timing behavior.

The method integrates well with the TTP/A protocol and is implementable in standard TTP/A slave and master nodes.

Even though configuration of new components is normally not time critical our method inherits a deterministic timing behavior from the TTP/A protocol and can be used in parallel with real-time traffic for hot plug and play of new nodes.

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