



**APPARATUS AND METHOD FOR SCHEDULING ONE OR MORE DATA
ACQUISITION REQUESTS**

5 The invention relates to an apparatus, a method and a computer program product for scheduling a prioritised data acquisition request of a plant asset management system. The invention also relates to an apparatus, a method and a computer program product for scheduling data acquisition requests of a plant asset management system. The invention also relates to an apparatus, a method and a computer program product for scheduling data acquisition requests in time slots.

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Plant asset management systems (hereinafter referred to as PAMs) implement the management of equipment modules and control modules in, say, an industrial process plant. PAMs allow for implementation of an audit trail of operations performed on equipment modules (such as field instrumentation) and control modules, and the online
15 adjustment and diagnosis of control modules.

With these functions, the management and maintenance tasks of equipment modules and control modules can be performed more efficiently.

20 PAMs typically communicate with items of plant equipment in order to monitor the equipment, whether to monitor a parameter the item of plant equipment is measuring (eg a flowmeter measures flow rate of fluid in a pipe), or to query the status of the plant equipment (eg, whether the flowmeter is in a “healthy” – that is good working order – state).

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Typically PAMs generate two types of data acquisition requests to items of field equipment. The first of these types is periodic requests (PRs). These are scheduled requests for data acquisition executed on a routine basis to a or each item of equipment within the plant. The PAM will routinely poll each field device. The second of these
30 types is “one-shot requests” (OSRs) where the PAM makes a non-routine request to the field equipment device for data acquisition therefrom. One example of a need for an OSR is when, say, a distributed control system flags a problem with the device or



another device or process associated with the device. The OSR is a prioritised data acquisition request.

PAMs include a scheduler module which schedules data acquisition requests in time slots. For instance, one known PAM schedules execution of data acquisition requests to field instrumentation in time slots of five-second duration. The number of data acquisition requests which may be executed in any one time slot is limited by constraints imposed by the communication protocol. A common number of requests for execution in a particular timeslot is 16. Thus, in any five-second time slot, a PAM (or a scheduler module of, or associated with, the PAM) schedules for execution a maximum of 16 data acquisition requests in each five-second time slot.

Existing PAMs arranged for one-shot requests to be scheduled and executed immediately upon receipt of the request at the PAM without considering the communication bandwidth and/or the network capacity. This is illustrated in the process 100 of Figure 1. A new request (for instance a one-shot update) 102 is generated and is sent for execution at step 104. A request 108 is transmitted to field device 106 and a return 110 from the field device 106 is received. The acquired data is sent back to the PAM at step 112.

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The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

Selective scheduling of the OSRs in dependence of a condition of the network may allow OSRs to be scheduled for execution at a time when the execution – i.e. transmission to a field device and safe return – may be ensured. This may provide particularly advantageous results if scheduling of the OSR is done in dependence of network traffic status. For instance, if the execution module detects that a batch of requests at a time slot has completed its execution early in the time slot, a recently-received OSR may be scheduled for execution in the same time slot. Consideration of traffic status of the network may allow for the OSR to be transmitted in a second

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transmission in the same time slot, being transmitted either on its own or as part of a batch of data acquisition requests. These techniques are discussed in more detail below.

By providing a scheduler module which schedules data acquisition requests of a plant asset management system in time slots according to a quota for the time slot, periodic requests (PRs) may be scheduled to make optimal use of network capacity instead, simply, of attempting to schedule all requests as and when they are received at the scheduler regardless of network capacity. This provides the distinct advantage optimisation of the communication network capacity likely obviates any delay in communication transactions – or in extreme circumstances – failure of the communication transactions where packets on the network are “dropped” – a situation which is particularly undesirable when the delayed /lost transactions are high-priority OSRs. Further, implementation of the techniques disclosed herein may enable the PAM to ensure the update speed for a data acquisition request is performed within the specified update period (i.e. the time slot).

In implementations where a quota of requests for a time slot is set where the quota is less than a network capacity of the maximum number of requests for each time slot then some capacity is reserved in the time slots for scheduling of higher-priority OSRs if/when received at the PAM. This seeks to obviate a situation where receipt, scheduling and execution of a OSR causes scheduled PRs to be missed thereby causing the periodical requests to become a missed request (MR). The MR will then later require re-scheduling by the scheduler. These techniques are also discussed in greater detail below.

The invention will now be described by way of example of and with reference to the accompanying figures in which:

Figure 1 is a schematic diagram illustrating a cycle of a OSR in a known PAM system;
Figure 2 is a system architecture diagram illustrating an apparatus for scheduling one or more data acquisition requests of a plant asset management system;

Figure 3 is a process flow diagram illustrating a first method for scheduling a prioritised data acquisition of a plant asset management system;

Figure 4 is a process flow diagram illustrating a second method for scheduling a prioritised data acquisition request of a plant asset management system;

- 5 Figure 5 is a process flow diagram illustrating a third method for scheduling a prioritised data acquisition request of a plant asset management system;

Figure 6 is a process flow diagram illustrating a method for scheduling data acquisition requests of a plant asset management system;

- 10 Figure 7 is a process flow diagram illustrating methods for scheduling and executing data acquisition requests.

Referring now to Figure 2, an architecture for an apparatus for scheduling one or more data acquisition requests will now be discussed in the context of an industrial process plant.

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System 200 comprises the apparatus 202 and PAM 204 for scheduling one or more data acquisition requests and plural field control stations 206 in communication with field instrumentation devices 214.

- 20 Alternatively, scheduler module 216/apparatus 202 is integral with – for example, installed within – PAM 204.

- Scheduler module 202 communicates with PAM 204 over data network 208 and/or through communications link 236. In the example of Figure 2, data network 208 is a
 25 Yokogawa™ Fieldbus™ for communication of data between the various devices of Figure 2. The devices communicate over the network 208 in, for example, the FF-H1 and/or HART protocols. Alternatively, (not shown), data network 208 may be a wireless network such as a WLAN or a WWAN. When scheduler module
 216 communicates with PAM 204 through communications link 236, this may be any
 30 suitable communications link such as a LAN or Ethernet. When scheduler 202 is integral with PAM 204, communications path 236 is an internal bus within PAM 204.

Principally, apparatus 202 comprises scheduler module 216. The scheduler module 216 may provide functionality as described below but, in summary, the scheduler module schedules a periodic request (a PR) in dependence of a condition of the network 208. Alternatively, apparatus 202 has sub-modules: Interface module 218, PR scheduler 224
5 and determination module 226 for performing the functions of scheduler module 216 as described below.

PAM 204 principally comprises a data acquisition request executor 234 for executing the data acquisition requests as scheduled by apparatus 202/scheduler 216. As a further
10 alternative, it will be appreciated that data acquisition request executor 234 may be provided as a module in the architecture of apparatus 202.

PAM 204 may also be provided with ancillary architecture such as memory 228, graphical user interface 230, and interface module 232 for providing the
15 communications interface for communication over data network 208 and/or over communications link 236.

Data network 208 provides a communications path for apparatus 202 and PAM 204 to communicate with field control stations 206. A field control station provides a station
20 in the field for local (that is, local to field instrumentation 214) marshalling of I/O cards 210. In one implementation, a field control station 206 can house up to 256 I/O cards 210 and each of 210 has the capacity to connect with up to a maximum of 40 field instruments 214.

25 It will be appreciated that the modules of Figure 2 may be implemented in their respective apparatus in software, hardware or combination thereof.

Prior to a detailed discussion of the process flow diagrams illustrated in Figures 2 to 5 below, it will be useful to have a discussion of the various types of data acquisition
30 requests generated by the PAM and scheduled by scheduler module 216 for execution by data acquisition request executor 234. System 200 of Figure 2 caters for at least

three types of requests: one-shot requests (OSR), periodical requests (PR), and missed requests (MR).

An OSR is given highest priority and is scheduled for execution in the first available
 5 time slot, subject to satisfaction of certain rules described below. Because of the high
 priority accorded a OSR, a PR may be required to be missed when a time slot is full and
 capacity in the time slot must be freed to schedule the OSR in that time slot. The
 missed PR thereby becomes a MR. These MRs must be re-scheduled at the earliest
 opportunity and are given next highest priority after OSRs. As discussed below, it may
 10 be possible for a MR to be caught with right away – that is, in the time slot it was
 originally scheduled for – as will be discussed below.

After the OSR and the MR, a PR is given next priority.

15 Figure 3 is a process flow diagram illustrating a first technique for scheduling a
 prioritised data acquisition request (a OSR) of a plant asset management system. The
 process 300 begins at step 302. At step 304, PAM 204 receives at interface 232 a new
 data acquisition request to a field instrument in a particular time slot which is denoted
 for the sake of convenience as time slot “x”. At step 306, executor module 234 makes a
 20 determination as to whether the new received request is a prioritised data acquisition
 request/OSR or not. When determination module 226 finds that the new request is not a
 OSR, the request is, in this example, by default a periodical request (PR) and it is then
 sent to PR scheduler 224 at step 308 for routine execution by executor 234 in the time
 slot, x+1. If executor module 234 determines the new request is a OSR at step 306,
 25 executor 234 then schedules, at step 312, the OSR in dependence of a condition of the
 network. The executor module 234 may then execute the OSR (not shown) After either
 step 308 or 312, at step 310, the time slot x+1 (i.e. the next time slot) becomes the
 current slot x, and the process loops around steps 304, 306, 308, 310 and 312.

30 Referring now to Figure 4, a second technique for scheduling a prioritised data
 acquisition request for the plant asset management system will now be discussed. The
 process 400 commences at step 402. PR scheduler module 224 has scheduled periodical

requests for batch execution at commencement of time slot x . That is, the scheduler module assigns an execution start time within a time slot to a periodic request. In one implementation of the technique of Figure 4, the batch of requests is executed at the start of time slot x , i.e. at $t = 0$ within the five-second time slot. At step 406, PAM 204
 5 either generates or receives at interface module 232 a new request at step 406. At step 408, executor module 234 determines whether or not the newly-received request is a OSR. As before with Figure 3, if the newly-received request is not a OSR it is determined to be a periodical request, and is simply sent to PR scheduler 224. Scheduler 224 schedules the PR to have a start time on the next time slot, $x+1$ at step 410 which
 10 executor 234 will use for execution. At step 412, the next time slot $x+1$ becomes the current time slot x , and the process reverts back to step 404.

If at step 408, executor module 234 determines the newly-received request is a OSR, the OSR is prioritised at step 414 for scheduling for execution by executor 234 in the next
 15 ($x+1$) time slot in dependence of a condition of the network.

At step 416, executor module 234 determines whether the current time slot x is an “early return” time slot. Executor 234 determines the time slot x is an early return time slot upon receipt of a return to a transmitted data acquisition request within a pre-
 20 determined duration of the first time slot; that is, when one or more requests for data acquisition to field instruments 214 are received at PAM 204 within a pre-determined duration of the first time slot. In one implementation of this technique, an early return in time slot x is detected by executor 234 when returns to all requests in a time slot are received within the pre-determined duration. In one example of this, the pre-determined
 25 duration by which the one/more than one/all requests must be returned is $t = 3$ seconds; i.e. at 3 seconds after commencement of the time slot and execution of the first batch of requests at $t = 0$.

If the current time slot is determined to be an early return time slot, executor module
 30 234 schedules the prioritised data acquisition request for execution in the early return time slot in a batch of requests if a capacity of the batch of requests is greater than a pre-determined percentage of a capacity of the first time slot. Thus, executor module 234

seeks to take immediate advantage of this opportunity for executing the one-shot request as a high priority rather than executing the OSR in time slot $x+1$ at step 424. However, this technique seeks to determine if the number of requests to be transmitted as a second batch in this first time slot x exceeds a pre-determined percentage of the capacity of the data network. A reason for this is that if the second batch of requests including the OSR is executed at, say, $t = 3$ seconds it is possible return from the field instruments 214 may not be received by $t = 5$ seconds, that is within the remainder of the five-second time slot. This could lead to communication loss/delay in time slot $x+1$ if network traffic from time slot x is still on the data network in time slot $x+1$. If the capacity of the requests to be executed in the second batch of data acquisition requests in time slot x is below a predetermined percentage of the channel capacity, the possible run-over into time slot $x+1$ is not worth the risk. Thus, it will be seen that executor module 234 executes the OSR in dependence of a traffic status of the network.

At step 418, executor 234 calculates the number of one-shot requests (and any other missed requests re-scheduled for execution from step 430 as will be discussed below) for possible execution in time slot x at step 418. The inventors have found that one predetermined percentage of network capacity which seeks to optimise performance to serve as a threshold in determining whether or not to proceed with the second batch request is 50% of data acquisition bandwidth. This capacity may be presented in terms of the maximum bandwidth (kbps) and/or the number of requests available for execution in the time slot. If considered in terms of bandwidth, if the communications data acquisition bandwidth in using either the FF-1/HART protocols is 30kbps, the executor module 234 determines to schedule for execution the second batch of requests if the capacity of the second batch of requests is greater than 15kbps. If considered in terms of the number of requests which may be executed in a particular time slot, 50% of the capacity of the five-second time slot is 8 requests. So, if the number of OSRs (and, optionally MRs) calculated for execution at step 418 exceeds 8, and/or the combined data rate of the requests exceeds 15kbps, the second batch with the OSRs/MRs is executed in time slot x at step 422. The process loops back to step 412 when the next time slot $x+1$ becomes the current time slot x . On the other hand, executor module 234 schedules the prioritised data acquisition request for execution in second time slot $x+1$ if

the first time slot is not an early return time slot (step 424) or if the capacity of the batch of requests is not greater than the pre-determined percentage of the capacity of the time slot. Thus, if the determination is made at step 420 that the capacity of the second batch is less than 50% of the network 208 capacity, the OSR/MSR batch is executed in time slot $x+1$ at step 424. At step 428, executor 234 determines if execution of the OSR in time slot $x+1$ would cause any PR scheduled for execution on time slot $x+1$ to be dropped; that is, whether a new MR in time slot $x+1$ will occur. If the determination of this is in the negative, the process loops back to step 412 where the next time slot $x+1$ becomes the current time slot x . If the determination module 226 determines that the OSR/MR will cause a PR to become a new MR, executor 234 schedules the new MR for execution in third time slot $x+2$ at step 430 before the process loops back to step 418 for re-scheduling of the MR. The bandwidth of the rescheduled MRs are calculated for execution in batch with any received OSRs at step 418 as described above and the process loops as described above also. Regardless of whether the time slot is an early return or not, a check is made on every time slot for execution of any MRs.

Figure 5 is a process flow diagram illustrating a third technique for scheduling a prioritised data acquisition request of a plant asset management system. Process 500 illustrates a technique for scheduling a single request and starts at step 502 where a new request (a one-shot update or periodic request) is received at step 504. At step 506, a determination is made as to whether the new request is a one-shot request. If the new request is not a one-shot request, it is a periodic request and it is scheduled for execution at step 526 and executed on time at step 528 before the process ends at step 520. If the new request is a one-shot request, this is prioritised for execution in the next execution time at step 508. At step 510 a determination is made as to whether or not the present time slot is an early return (or “catch up”) time slot. If this is not an early return time slot, the request is executed on current execution time at step 524 before the process ends at step 520. If the current time slot is an early return time slot, the number of requests in the current execution time (the one-shot plus missed request) are calculated at step 512 and, if this calculated number is at least 50% of the bandwidth at step 514 the request is executed on this early time slot at step 516 prior to the process ending at step 520. If, at step 514, the number of requests is less than 50% of the bandwidth the

process waits at step 522 for the next on time execution prior to the process ending at 520.

Figure 6 provides an illustration of a technique for scheduling data execution requests of a plant asset management system. Process 600 starts at step 602. At step 604, interface module 218 of scheduler module 216 receives multiple routine (periodic) data acquisition requests. At step 606, determination module 226 makes a determination as to whether the number of requests is greater than the quota for the current time slot. The quota may be the maximum capacity of the network – say, 16 requests for a particular five-second time slot – or it may be set at a predetermined percentage of the maximum capacity. This is discussed below. If the number of the requests is less than the quota for the time slot, all multiple requests are simply scheduled by scheduler module 216 in the next time slot at step 612 and the process loops back to step 604 to wait for the receipt of the next batch of multiple requests.

If, at step 606, the number of requests to be scheduled is greater than the quota for the time slot, PR scheduler module 224 schedules a request for the current time slot up to the quota at step 608. PR scheduler 224 assigns an execution start time within the time slot for the periodic request, say at $t = 0$. After filling up the quota at step 608, PR scheduler 224 schedules the remaining requests for the next time slot, $x+1$. The process loops back to 611, where the next time slot $x+1$ becomes the current time slot x , and to step 606 where a determination is made whether the number of remaining requests is greater than the quota for (what is now) the current time slot, when the process loops around step 606, 608, 610 until a determination is made that the number of requests to be scheduled is less than the quota for the present time slot, whereupon PR scheduler 612 schedules a request for the current time slot.

The scheduler also provides the functionality for checking for a least-occupied time slot and scheduling a PR in the least-occupied time slot.

Assuming each five-second time slot can handle 16 requests,

In a first example:

Time slot $t=0$ is already occupied with (i.e. the scheduler has already scheduled for execution in this time slot) 10 requests

$t=5$ is occupied with 0 request

5 $t=10$ is occupied with 5 requests

$t=15$ is occupied with 8 requests

If scheduler module 224 receives a new PR for scheduling, scheduler module 224 recognises that the time slot at $t=5$ is the least occupied and schedules the new PR for execution on time slot $t=5$.

In a second example:

$t=0$ occupied with 10 requests

$t=5$ occupied with 0 request

15 $t=10$ occupied with 8 requests

$t=15$ occupied with 5 requests

If scheduler module 224 receives 20 new PRs for scheduling, the first 16 are scheduled for execution at $t=5$ (thereby filling this time slot) and the next 4 are scheduled for execution at $t=15$ as that time slot is then the next least-occupied time slot after filling of time slot $t=5$.

Referring now to Figure 7, methods for scheduling and executing data acquisition requests are illustrated. Interface module 232 of PAM 204 receives a request and makes a determination as to whether or not the request is a OSR. If the request is a OSR, the request is passed to executor 234 for execution. If the request is not a OSR it is passed to the scheduler 216 for scheduling. After scheduler 216 schedules the request, the request is returned to executor 234 for execution.

30 A more detailed discussion of the execution is now given. Once a request has been passed to executor 234 for execution, executor 234 waits for an execution. A determination is made as to whether the time slot is early return or not. If the slot is an

early return, the OSRs and MRs are calculated. If the calculated OSRs/MRs is greater than or equal to 50% of the bandwidth, these requests are then executed. If the bandwidth calculation yields a result of less than 50%, the process loops back to wait for execution.

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If the time slot is not early return, requests are selected for execution; OSRs and MRs are prioritised over PRs. Next, a determination is made as to whether the OSRs/MRs causes any PRs to become new MRs. If yes, the PR to be missed is set to an MR and the selected request are executed.

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Turning now to the scheduler 216, PR requests are received by the scheduler. The least-occupied time slot is searched for and requests are scheduled accordingly. The process loops if further requests are to be scheduled until a determination is made that no further requests are left, before the process ends.

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It will be appreciated that the invention has been described by way of example only and that various modifications in detail may be made without departing from the spirit and scope of the appended claims. It will also be appreciated that features of one aspect of the invention may be presented in combination with features of another aspect of the

20 invention.

CLAIMS

1. Apparatus for scheduling a prioritised data acquisition request of a plant asset management system, the plant asset management system being configured to
5 communicate with a field device over a network, the apparatus comprising an execution module configured to schedule the prioritised data acquisition request in dependence of a condition of the network.
2. Apparatus according to claim 1, wherein the execution module is configured to
10 schedule the prioritised data acquisition request in dependence of a traffic status of the network.
3. Apparatus according to claim 1 or claim 2, wherein the execution module is configured to schedule prioritised data acquisition requests in time slots and to
15 determine a time slot is an early return time slot.
4. Apparatus according to claim 3, wherein the execution module is configured to determine a first time slot is an early return time slot upon receipt of a return to a transmitted data acquisition request within a pre-determined duration of the first time
20 slot.
5. Apparatus according to claim 3 or claim 4, wherein the execution module is configured to schedule the prioritised data acquisition request in the early return time slot in a batch of requests if a capacity of the batch of requests is greater than a pre-
25 determined percentage of a capacity of the first time slot.
6. Apparatus according to any of claims 3 to 4, wherein the execution module is configured to schedule the prioritised data acquisition request in a second time slot if the first time slot is not an early time slot or if the capacity of the batch of requests is not
30 greater than the pre-determined percentage of the capacity of the first time slot.

7. Apparatus according to claim 6, wherein the execution module is configured to determine if scheduling of the prioritised data request in the second time slot would cause a missed request from the second time slot.
- 5 8. Apparatus according to claim 7, wherein the execution module is configured to schedule the missed request in a third time slot.
9. Apparatus according to claim 5, wherein the execution module is configured to schedule the prioritised request in the batch of requests further comprising a re-
- 10 scheduled missed request.
10. Apparatus according to any preceding claim, wherein the apparatus further comprises a scheduler module configured to schedule periodic data acquisition requests in time slots and to:
- 15 determine whether a number of the periodic data acquisition requests is greater than a quota for a first time slot;
- to schedule periodic data acquisition requests in the first time slot to fill the quota; and
- to schedule remaining periodic data acquisition requests in a second time slot.
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11. Apparatus for scheduling data acquisition requests of a plant asset management system, the apparatus comprising a scheduler module configured to schedule the data acquisition requests in time slots, wherein the scheduler module is further configured to:
- determine whether a number of the data acquisition requests is greater than a
- 25 quota for a first time slot;
- to schedule requests in the first time slot up to the quota; and
- to schedule remaining requests in a second time slot.
12. Apparatus according to claim 10 or claim 11, wherein the scheduler module is
- 30 configured to assign an execution start time within a time slot to a periodic request.

13. Apparatus according to any of claims 10 to 12, further configured to determine a least-occupied time slot for scheduling a data acquisition request for execution therein.
14. Apparatus for scheduling data acquisition requests of a plant asset management system in time slots, the apparatus comprising a scheduler module configured to determine a least-occupied time slot for scheduling a data acquisition request for execution therein.
15. A method of scheduling a prioritised data acquisition request of a plant asset management system, the plant asset management system being configured to communicate with a field device over a network, the method comprising scheduling the prioritised data acquisition request in dependence of a condition of the network.
16. A method of scheduling a prioritised data acquisition request of a plant asset management system using the apparatus of any of claims 1 to 10.
17. A method of scheduling data acquisition requests of a plant asset management system, comprising scheduling the data acquisition requests in time slots, and further comprising:
- determining whether a number of the data acquisition requests is greater than a quota for a first time slot;
 - scheduling requests in the first time slot to fill the quota; and
 - scheduling any remaining requests in a second time slot.
18. A method of scheduling data acquisition requests of a plant asset management system using the apparatus of any of claims 11 to 14.
19. A method for scheduling data acquisition requests of a plant asset management system in time slots, comprising determining a least-occupied time slot for scheduling a data acquisition request for execution therein.

20. A computer program product comprising computer code stored thereon or embedded therein for executing the method of any one of claims 15 to 19.