The invention relates to a hierarchical synchronization method for a telecommunications system employing message-based synchronization and to a telecommunications system employing message-based synchronization and comprising a plurality of nodes (1...6) interconnected by transmission lines. In the method, the nodes interchange signals containing synchronization messages with information on the priority of the respective signal in the internal synchronization hierarchy of the system. In order to speed up resynchronization in failure situations, when the node loses the selected timing source, it attempts to select as a new synchronization source a neighboring node transmitting a synchronization signature which is on the same level in the synchronization hierarchy of the system as the synchronization signature of the lost timing source and which is closer to the master node of the system than the node itself, whereby when such a node is found, the node selects it as its new synchronization source, or if such a node is not found, the node starts a procedure known per se for finding a new connection to the master node.
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A hierarchical synchronization method and a telecommunications system employing message-based synchronization

The invention relates to a hierarchical synchronization method for a telecommunications system employing message-based synchronization and comprising a plurality of nodes interconnected by transmission lines, wherein the nodes interchange signals containing synchronization messages with information on the priority of the respective signal in the internal synchronization hierarchy of the system.

The invention also relates to a telecommunications system employing message-based synchronization and comprising a plurality of nodes interconnected by transmission lines over which the nodes interchange signals containing synchronization messages with information on the priority of the respective signal in the internal synchronization hierarchy of the system.

As used in the text below, the term node refers to a junction point between transmission lines in a system. A node may be any device or equipment capable of affecting clock synchronization, such as a branching or cross-connection means.

Nodes in a system utilizing message-based synchronization are interconnected by transmission lines which the nodes use for data transmission. These lines also forward the clock frequency of the transmitting party to the receiving party. Each node selects the frequency of a signal from a neighbouring node or the frequency of its own internal clock source as the source of its own clock frequency. In order that all nodes in the system would operate at the same clock frequency, one usually attempts to make the
system to synchronize itself with a single clock source called a master source. All system nodes connected directly to the selected master source are thus synchronized with the master source while nodes connected to the nodes adjacent to the master source but not directly connected to the master source are synchronized with these adjacent nodes. Accordingly, each node at a greater distance from the master source synchronizes itself with a node one node spacing closer to the master source.

In order that the above-described synchronization hierarchy could be established within the system, the system nodes interchange synchronization messages. These messages contain information by means of which individual nodes are able to select a timing source. The system nodes are prioritised and the system tends to synchronize itself with the clock frequency of a node having the highest level of priority. Normally each priority level is assigned to a single system node. Synchronization messages normally contain information about the origin of the clock frequency of the node transmitting the message and the priority of the node as well as a value describing the quality of the clock signal. Accordingly, a neighbouring node clock frequency which originates from a desired node and which is of the highest quality can be selected by an individual node as the source of its own clock frequency. At the system start-up each node selects its own internal clock source as the source of its clock frequency as it has not yet processed any incoming synchronization messages. After the node has processed the first incoming synchronization messages, it selects the clock frequency of a neighbouring node having the highest level of priority as the source of its clock
frequency. After all messages have been distributed over the system and the system has achieved a stable state as far as synchronization is concerned, the system has been synchronized hierarchically with the clock frequency of the master source.

Figure 1 shows a system utilizing message-based synchronization in a stable situation. Priorities assigned to the nodes are indicated by numbers within the circles representing the nodes. The smaller the number, the higher the priority of the node. Synchronization messages transmitted by a node n (n = 1...6) are indicated by the reference MSGn. Synchronization messages transmitted by different nodes usually differ from each other and depend on the applied message-based synchronization method. The distribution of the clock frequency from the master clock (node 1) to the other system nodes is illustrated by solid lines. Internodal connections drawn by broken lines are not used in a normal situation for system synchronization, but they are available in change situations.

Message-based synchronization is based on a simple principle that the user defines the synchronization hierarchy of the nodes by assigning each node a dedicated signature indicating the hierarchical level of the node, and the system synchronizes itself with the defined master clock independently by utilizing, if required, all existing internodal connections (cf. Figure 1). If the connection to the master clock breaks, and no alternative connection exists, or if the master clock fails, the system synchronizes itself with a node of the next highest level of hierarchy. Figure 2 shows a situation where the master clock fails in the system according to Figure 1. Response to the change in synchronization
takes place by message interchange between nodes. When
the timing source of the node fails, the synchroniza-
tion hierarchy is reestablished beginning from the
point of break (away from the master device of the
system). This takes place e.g. in such a manner that
the node that detects the break first enters into a
state of internal timing for a preset time period and
then forwards information about the change. When the
next node detects the changed situation, it also
enters into a state of internal timing for a preset
time period and forwards information about the change,
etc. After the expiry of the preset time periods of
the individual nodes, the reestablishment of the
synchronization hierarchy starts. The resulting
hierarchy is usually similar to the original hier-
archical structure where the failed connection is
replaced with an operative one while the structure
otherwise remains nearly unchanged.

A network utilizing message-based synchroniza-
tion is described e.g. in US Patents 2,986,723 and
4,837,850. The former patent discloses a system in
which the nodes enter in failure situations into a
state of internal timing as described above. The
latter patent discloses a system in which re-
synchronization after a failure situation is based on
a separate master node paging message transmitted in a
failure situation. These systems will be described
more closely below.

In the prior art systems the reestablishment of
synchronization after a failure situation described
above takes plenty of time as it usually requires
(depending on the network topology and the location of
the failure) several successive transitions into
internal timing as well as several changes in the
synchronization tree, or alternatively, transmission
of separate paging messages. (The synchronization tree refers to a hierarchical tree-like structure established in the network beginning from the master node in master-slave synchronization).

The object of the present invention is to provide a hierarchical synchronization method which speeds up resynchronization after the node has lost the timing source selected by it. This is achieved by a method according to the invention, which is characterized in that when the node loses the selected timing source, it attempts to select as a new synchronization source a neighbouring node transmitting a synchronization signature which is on the same level in the synchronization hierarchy of the system as the synchronization signature of the lost timing source and which is located closer to the master node of the system than the node itself, whereby when such a node is found, the node selects it as its new synchronization source, or if such a node is not found, the node starts a procedure known per se for finding a new connection to the master node. A telecommunications system according to the invention, in turn, is characterized in that each system node comprises means for storing as a separate group incoming synchronization signatures having the same level in the synchronization hierarchy of the system as the synchronization signature of the current selected timing source and located closer to the master node of the system than the node itself. (The node may lose its source of timing either when the signal disappears or the signal quality deteriorates so that the signal cannot/must not any longer be used for synchronization, or when the selected synchronization message deteriorates. A deteriorated synchronization signature, in turn, means that the respective synchronization message is still
acceptable in quality but the level of priority of the associated signature has deteriorated. Deterioration in an incoming synchronization signature is indicative of a change/failure in a connection to the master source of the system.)

The invention rests on the idea that if a node, when it loses its timing, has a neighbouring node on the same level in the synchronization hierarchy as the node from which the lost timing was derived, and this neighbouring node is closer to the master node than the node that lost its timing, the neighbouring node can be selected as the new timing source. In this way it is possible to significantly speed up resynchronization with the master clock of the system.

In the following the invention will be described in more detail with reference to the examples shown in Figures 3 to 6 in the attached drawings, in which

Figure 1 shows the general configuration of a system employing message-based synchronization when the system is in synchronization with the clock frequency of a master source;

Figure 2 shows the network of Figure 1 when the master node has failed;

Figure 3 shows a network employing self-organizing master-slave synchronization (SOMS) in an initial state;

Figure 4 shows the network of Figure 2 in a stable state;

Figure 5 is a flow chart illustrating the principle according to the invention;

Figures 6 and 7 illustrate a SOMS network applying the method according to the invention; and

Figure 8 shows synchronizing means provided in a node for realising the method according to the invention.
Figure 3 illustrates a system employing self-organizing master-slave synchronization (SOMS), a prior art message-based synchronization method. In this specific case, the system comprises five nodes (or devices) assigned SOMS addresses indicated by the reference numerals 1...5 according to their level of hierarchy. (The master node of the system has the smallest SOMS address.) The nodes interchange messages containing such SOMS addresses. In this way the nodes are able to identify each other by means of the address numbers and establish a synchronization hierarchy so that the whole network can synchronize itself with the master node.

As mentioned above, messages transmitted continually in the network are dependent on the applied message-based synchronization method. In addition, the messages are specific for each transmitting node. In the SOMS network a synchronization message contains three different parts: a frame structure, signature and check sum. The SOMS signature is the most important part of the SOMS message. It comprises three consecutive numbers D1 to D3:

D1 is the origin of the synchronization frequency of a node transmitting a SOMS message, i.e. the SOMS address of a node appearing as a master node to the transmitting node.

D2 is a distance to a node indicated by D1. The distance is given as the number of intermediate nodes.

D3 is the SOMS address of a transmitting node.

Each node (or device) compares continuously incoming SOMS signatures with each other and selects the smallest amongst them. In the signature the different parts D1, D2 and D3 are combined into a single number by placing them in succession (D1D2D3) (for the sake of clarity, a dash will be inserted
between the different parts in the text below as follows: D1-D2-D3). Accordingly, a primary criterion for the selection of the smallest address is the SOMS address (D1) of a node appearing as the master node to the preceding nodes, i.e. the node tends to be synchronized with a signal having a frequency originally derived from a node with the smallest possible address. In a stable situation, the whole network is thus synchronized with the same master node (as the master node of the whole network has the smallest SOMS address).

If two or more of the incoming signals are synchronized with the same master node, the one arriving over the shortest path (D2) is selected. The last criterion for selection is the SOMS address (D3) of the node transmitting the SOMS message, which is used for the selection if the incoming signals cannot be distinguished from each other in any other way.

After the node has accepted one of the neighbouring nodes as its new synchronization source on the basis of an incoming SOMS signature, it has to regenerate its own SOMS signature. The new SOMS signature can be derived from the selected smallest SOMS signature as follows: the first part (D1) is left intact; the second part (D2) is incremented by one, and the third part (D3) is replaced with the node's own SOMS address.

Each node also has its own internal SOMS signature X-0-X, where X is the SOMS address of the node. If none of the incoming SOMS messages contains a signature smaller than the internal signature, the node uses its own internal oscillator or possibly a separate synchronization input as the source of clock frequency. Of course, the outgoing SOMS message thereby employs the internal SOMS signature.
The nodes transmit continuously SOMS messages in all directions in order that any changed data in the SOMS signatures would be distributed as rapidly as possible and that they would know the current operating condition of neighbouring nodes. The SOMS signatures cannot be compared with each other until the incoming SOMS messages have been accepted and the SOMS signatures have been extracted from the messages.

When the first SOMS message is received from a specific transmission line, the SOMS signature contained therein is accepted immediately for comparison if the message is faultless. When the incoming transmission line has an accepted SOMS signature and faultless messages containing the same signature are received continuously, the situation remains unchanged. If the SOMS message is found to be faulty, the current SOMS signature is retained until three successive faulty SOMS messages have been received. At this stage the old SOMS signature is no longer accepted for comparison. Waiting for three successive SOMS messages aims at eliminating temporary disturbances.

If no SOMS message is received from the line and there is no line failure, the current SOMS signature is rejected only after a period of time corresponding to three successive SOMS messages. If the line fails totally, the SOMS signature is rejected immediately. If no appropriate SOMS signature is available for comparison due to disturbances in the incoming signal, the SOMS signature of the transmission line is rejected. A constant-value signature where all parts (D1, D2, D3) have their maximum value (MAX-MAX-MAX) is thereby used in the comparison as the SOMS signature of this incoming transmission line.

When a new changed SOMS signature is detected in an incoming SOMS message, it is accepted immediately
for comparison, if the message is faultless. In this way there will be no unnecessary delays in network changes.

Initially each node employs its own internal synchronization source, and transmits its own internal SOMS signature X-0-X to the other nodes. This signature is also compared with incoming SOMS signatures. If none of the incoming signatures is smaller than the internal signature, the node continues to use its own internal timing.

In Figure 3, the SOMS network is shown in an initial state when none of the nodes (or devices) has yet processed any one of the incoming SOMS messages. In all nodes, the highest priority is assigned to the internal SOMS signature of the node as no other signatures have yet been processed. In Figure 3, the SOMS signatures are indicated beside each node to which they are transmitted, and the selected signature is framed (in the initial situation shown in Figure 3 all nodes employ their internal timing source). Lines used in synchronization are drawn by a continuous line and standby lines are drawn by a broken line (in the initial situation shown in Figure 3, all lines are standby lines).

When the nodes start to process the incoming SOMS messages, node 1 retains the use of the internal timing, nodes 2 and 4 synchronize themselves with node 1 on the basis of the signature 1-0-1, node 3 is synchronized with node 2 (2-0-2), and node 5 with node 3 (3-0-3). At the same time the nodes generate their own new SOMS signatures as described above and provide their outgoing SOMS message with the new signature. The network in a stable situation is shown in Figure 3. All nodes have synchronized with the master node 1 over the shortest possible path.
In the synchronization method disclosed in the above-mentioned US Patent 2,986,723, a system node that has lost its synchronization connection changes over to internal timing (to use its own oscillator) for a preset time period and transmits its own internal timing signature X-O-X (where X is the node's own synchronization number, as described above) to the neighbouring nodes. When a neighbouring node receives a signature indicating internal timing from a node through which it has been synchronized, it also changes over to internal timing for a preset time period and starts to transmit its own internal timing signature Y-O-Y to the neighbouring nodes. After the forced time period of an individual node has expired, it again selects freely the source of its timing from amongst the incoming signals by utilizing the incoming synchronization messages, so that the structure of the synchronization hierarchy begins to be reestablished within a system portion below the point of failure so far as synchronization is concerned.

Accordingly, when the synchronization structure is lost as a result of a failure in a transmission line or a node, part of the system nodes obtain timing from their own clock, which is seldom equal in quality to the master clock of the system.

In the synchronization method disclosed in the above-mentioned US Patent 4,837,850, a device (node) that has lost its synchronization connection transmits a paging message so as to page the master device while acting as a master clock for devices which derived synchronization through it before the failure situation. When the other devices receive the paging message transmitted by the device that detected the failure, they forward the message. If the paging message finally reaches the master device of the
system, the master device transmits its own normal synchronization message. As this synchronization message reaches the device that detected the failure, a new synchronization connection has been established to the master device over an alternative path. The system operates similarly if one device (node) fails, and so the devices below the device with false synchronization lose their connection to the master device of the system.

In a system employing the synchronization method disclosed in US Patent 4,837,850, a failure of a synchronization connection or of a device (node) located centrally in the synchronization hierarchy causes a break in the synchronization structure so that the system is divided into two portions so far as synchronization is concerned. One portion uses the clock frequency of the master device as the clock frequency while the other portion uses the clock frequency of the device that detected the failure. After a new path has been found to the master device of the system by means of a paging message and information thereon has returned to the device that detected the failure, the entire system again obtains timing from the master device.

In the solution according to the invention, the resynchronization of the system to the master clock is speeded up in failure situations. Figure 5 shows a flow chart illustrating the operation of a system node when it detects a deterioration or break in the signal selected for synchronization or a deterioration in the selected synchronization signature, which may be caused e.g. by a failure of the connection used by the selected signal or of a node transmitting the signal. When the loss of the selected timing source is detected at stage 51, the node checks whether there is
another signature of equal level amongst the other incoming synchronization signatures (stage 52). If such an signature is found, it is determined whether the node transmitting this signature is closer to the master node in the synchronization tree (stage 53). If so, the signal of this signature is accepted immediately as the new timing source of the node. On the contrary, if the comparison at stage 52 or 53 yields a negative result, the procedure known per se is started immediately so as to find an alternative path to the master node. In the SOMS network, this means that the node enters into the state of internal timing for a preset time period.

As the node transmitting the synchronization signature equal in level to the previously selected synchronization signature should also be closer to the master node in the synchronization tree than the node that detected the failure, it may be necessary, depending on the applied synchronization method, to insert an additional element into the synchronization message in order that the nodes would know each other's location on the hierarchical levels of the synchronization tree. If the network uses the self-organizing master-slave synchronization (SOMS) described above, the information is transmitted automatically with the synchronization signature (the second number in the signature, that is, D2). On the contrary, if the system disclosed e.g. in US Patent 4,837,850 is used, the generation and forwarding of this information have to be added to the system. In practice, this takes place similarly as in the SOMS network, that is, an element indicating distance is added to the message. The master node gives the element the value zero, and each node then increments the value by one when it forwards the message of the
master node.
The transmitting node has to be closer to the master node in the synchronization tree than the node that detected the failure as the situation otherwise may result in the formation of a synchronization loop, that is, the device is synchronized with a signal the frequency of which has already passed through the device.

Figures 6 and 7 illustrate the implementation of the method according to the invention in a network utilizing the above-described self-organizing master-slave synchronization (SOMS). The network comprises six nodes 1...6. A failure of the connection between nodes 2 and 4 causes node 4 to lose the connection to node 2. In this case node 4 will not be forced into the state of internal timing but it immediately accepts the synchronization signature (1-1-3) from node 3, which signature is on the same level of hierarchy as the previously selected signature (1-1-2). Thus the synchronization signature transmitted by node 4 will not change (cf. Figure 7) nor do there occur any changes in the synchronization tree below it. In this way, any forced transitions into the state of internal timing will be avoided, thus speeding up the synchronization as there may be several such transitions, depending on the situation and the network topology. Accordingly, any unnecessary network changes are avoided as the nodes will not enter into the state of internal timing one after another.

Temporary disturbances will be filtered off as a faulty synchronization message has to be received three times before the incoming synchronization signature is rejected.

Correspondingly, the method according to the invention may be utilised in any system in which a
specific node has at least two neighbouring nodes which are equally distant from the master node of the system (and closer to it than this specific node).

The acceptance of a synchronization signature of equal level to replace the previously selected signature is performed in the synchronization decision means of the node. Figure 8 illustrates means provided in a node for selecting a source of timing. The figure shows two signals A and B received at a system device from neighbouring devices. Both signals originate from the system's own node and contain a synchronization message which is separated by a signal reception means 13a and 13b, respectively, and then forwarded to an associated synchronization message reception means 16a and 16b, respectively. The synchronization message reception means checks that the message is faultless and forwards it to a centralized synchronization decision means 20 having each one of its inputs connected to the output of the respective reception means 16a, 16b. The signal reception means also monitor the quality of the received signal and store information thereon in interface-specific fault databases 24a and 24b, respectively. The synchronization message reception means 16a obtains fault data from the database 24a, and the reception means 16b from the fault database 24b, respectively. If the incoming signal is not of adequate quality for synchronization, the synchronization message reception means prohibits the use of the signal. This may be done separately by prohibiting or by setting the value of the incoming signature to its maximum, so that, in the latter case, the signature will not in any case be used for synchronization.

The decision means 20 compares the messages and stores them in a memory 21. When the previously
selected synchronization signature deteriorates or is lost totally, the decision means searches the other signatures for an signature equal in level in the synchronization hierarchy. If such an signature is found, the decision means 20 finds out whether the node transmitting this signature is closer to the master node in the synchronization tree than the node itself. If so, the decision means selects the signal corresponding to this signature as its new timing source. If no signature meeting the criteria is found, the decision means starts the normal, slower procedure for finding a connection to the master node of the system. The messages may also be stored in the memory 21 in priority order so that the highest status is assigned to the current clock source having the "best" synchronization signature according to the applied message-based synchronization method. When the previously selected synchronization signature is lost, the next signature on the list is selected immediately, if it is marked as meeting the above-mentioned criteria. Accordingly, the comparison (Figure 5, stages 52 and 53) need not be carried out only after the loss of timing but it can be carried out continuously so that when the timing is lost it is immediately known whether a new signature can be selected immediately or whether the prior art, slower method has to be started to find an alternative path to the master node. The synchronization signatures may also be listed separately in the memory 21 so that the first list comprises all incoming synchronization signatures, and the second list first comprises the selected synchronization signature and all signatures meeting the above-mentioned criteria then are listed below it in priority order. When the node loses the synchronization signature that it has selected, it is
immediately able to select the next signature from the second list.

After a neighbouring node meeting the above-mentioned criteria is found, the node may also have a predetermined short filtering time before it selects the synchronization signature of the neighbouring node. This is advisable in larger systems in particular, as the loss of timing may be due to a failure occurred at a greater distance in the network. In such a case the failure may affect another signature of equal level somewhat later. The purpose of the filtering time is to prevent the node from selecting an signature which is about to be affected by the failure. In practice, the length of the filtering time is e.g. half of the time required to detect a change and respond to it over one connection.

Even though the invention has been described above with reference to the examples of the attached drawings, it is obvious that the invention is not restricted to it but it may be modified within the inventive idea disclosed above and in the attached claims. The method according of the invention may be used e.g. in connection with different message-based synchronization methods even though it is best suited for a SOMS network as the synchronization message used in the SOMS network is as such optimal for the solution according to the invention.
1. Hierarchical synchronization method for a telecommunications system employing message-based synchronization and comprising a plurality of nodes (1...6) interconnected by transmission lines, wherein the nodes interchange signals containing synchronization messages with information on the priority of the respective signal in the internal synchronization hierarchy of the system, characterized in that when the node loses the selected timing source, it attempts to select as a new synchronization source a neighbouring node transmitting a synchronization signature which is on the same level in the synchronization hierarchy of the system as the synchronization signature of the lost timing source and which is located closer to the master node of the system than the node itself, whereby when such a node is found, the node selects it as its new synchronization source, or if such a node is not found, the node starts a procedure known per se for finding a new connection to the master node.

2. Method according to claim 1, characterized in that if a neighbouring node meeting said criteria is found, the node accepts it directly as its new timing source as soon as the timing is lost and said new neighbouring node is found.

3. Method according to claim 1, characterized in that if a neighbouring node meeting said criteria is found, the node accepts it as its new timing source after the elapse of a predetermined filtering period from the time of losing the timing and finding said new neighbouring node, provided that the signature of the neighbouring node has not changed
during said period.

4. Method according to claim 2, characterized in that the node lists continuously all neighbouring nodes meeting said criteria, whereby a replacing synchronization signature is known whenever the selected synchronization signature is lost.

5. Telecommunications system employing message-based synchronization and comprising a plurality of nodes (1...6) interconnected by transmission lines over which the nodes interchange signals containing synchronization messages with information on the priority of the respective signal in the internal synchronization hierarchy of the system, characterized in that each system node comprises means (20, 21) for storing as a separate group incoming synchronization signatures having the same level in the synchronization hierarchy of the system as the synchronization signature of the current selected timing source and located closer to the master node of the system than the node itself.

6. System according to claim 5, characterized in that said synchronization signatures are stored in a memory in priority order.
FIG. 1

FIG. 2
FIG. 3

FIG. 4
FIG. 5

SELECTED TIMING SOURCE LOST

51

ANY OTHER SIGNATURE OF EQUAL LEVEL?

52 NO

YES

IS THE NODE TRANSMITTING THE SIGNATURE CLOSER TO THE MASTER NODE IN THE SYNC TREE?

53 NO

YES

ACCEPT NEW SIGNATURE DIRECTLY

54

START NORMAL PROCEDURE TO FIND ALTERNATIVE CONNECTION TO MASTER NODE

55
FIG. 6

FIG. 7
FIG. 8
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

**IPC5:** H04J 3/06

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**IPC5:** H04J, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
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<tr>
<td>X</td>
<td>EP, A2, 0435395 (PHILIPS PATENTVERWALTUNG GMBH), 3 July 1991 (03.07.91), column 26; column 27</td>
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<td>P.A</td>
<td>EP, A1, 0553360 (FUJITSU LIMITED), 4 August 1993 (04.08.93)</td>
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<td>EP, A2, 0262705 (PHILIPS PATENTVERWALTUNG GMBH), 6 April 1988 (06.04.88)</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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<th>Date of mailing of the international search report</th>
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<td>15 February 1994</td>
<td>21-02-1994</td>
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NILS EKSTRÖM
Telephone No. +46 8 782 25 00

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<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
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<td>US-A- 4837850</td>
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