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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
61/144,676	01/14/2009		220	E090002USP1		

CONFIRMATION NO. 3694

FILING RECEIPT



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77330
ENTROPIC COMMUNICATIONS, INC.
6290 SEQUENCE DRIVE
SAN DIEGO, CA 92121

Date Mailed: 01/30/2009

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Applicant(s)

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Power of Attorney: None

If Required, Foreign Filing License Granted: 01/27/2009

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/144,676**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

Title

Method and apparatus using of range estimates to improve efficiency in a home entertainment network over coaxial cable

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	E090002USP1
		Application Number	
Title of Invention	METHOD AND APPARATUS USING OF RANGE ESTIMATES TO IMPROVE EFFICIENCY IN A HOME ENTERTAINMENT NETWORK OVER COAXIAL CABLE		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

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☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
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Applicant 1				
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All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button.			Add

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Customer Number	77330		
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Application Information:

Title of the Invention	METHOD AND APPARATUS USING OF RANGE ESTIMATES TO IMPROVE EFFICIENCY IN A HOME ENTERTAINMENT NETWORK OVER COAXIAL CABLE		
Attorney Docket Number	E090002USP1	Small Entity Status Claimed	☐
Application Type	Provisional		
Subject Matter	Utility		
Suggested Class (if any)		Sub Class (if any)	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	9	Suggested Figure for Publication (if any)	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐ Request Not to Publish. I hereby request that the attached application not be published under 35 U.S. C. 122(b) and certify that the invention disclosed in the attached application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	E090002USP1
		Application Number	
Title of Invention	METHOD AND APPARATUS USING OF RANGE ESTIMATES TO IMPROVE EFFICIENCY IN A HOME ENTERTAINMENT NETWORK OVER COAXIAL CABLE		
Customer Number	77330		

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Prior Application Status				Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	

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Application Number	Country ⁱ	Parent Filing Date (YYYY-MM-DD)	Priority Claimed	
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Assignee Information:

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Signature:

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number		E090002USP1	
		Application Number			
Title of Invention		METHOD AND APPARATUS USING OF RANGE ESTIMATES TO IMPROVE EFFICIENCY IN A HOME ENTERTAINMENT NETWORK OVER COAXIAL CABLE			
Signature	/Bruce W. Greenhaus/			Date (YYYY-MM-DD)	2009-01-14
First Name	Bruce W.	Last Name	Greenhaus	Registration Number	37339

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P A T E N T
Docket: E090002USP1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION

Title:

**METHOD AND APPARATUS USING OF RANGE ESTIMATES TO IMPROVE
EFFICIENCY IN A HOME ENTERTAINMENT NETWORK OVER COAXIAL CABLE**

Inventor(s):

Arndt J. Mueller

Ronald B. Lee

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Attorney Docket No.: E090002USP1

Sheets of Drawings: 9

Method and apparatus using of range estimates to improve efficiency in a home entertainment network over coaxial cable

Background

A standards setting body, referred to as the Multimedia over Coax Alliance (MoCA), has established an industry standard for transmitting information at high speeds over coaxial cable. This standard is used in particular to allow devices connected to a home entertainment network to communicate with one another. The protocol established by MoCA includes a layered approach, in which the first layer is the physical (PHY) layer and the second layer is the Media Access Control (MAC) layer. The MAC layer protocol relies on a network coordinator (NC) to schedule all traffic on the network to avoid packet collisions. In order to accomplish this scheduling, the NC and each node in the network maintains a local channel time clock (CTC) counter. All nodes are responsible for synchronizing their CTC counts to that of the NC. The accuracy of this network wide CTC synchronization is one factor that determines the duration of an inter-frame gap (IFG). The IFG is the amount of time between packets.

In the prior art, the internal CTC resolution has been increased. However, the CTC resolution signaled across a c.LINK+ network remains at 20 nsec. Reducing the 20 nsec resolution for purposes of scheduling will provide a negligible throughput improvement (i.e. even if only the shortest possible c.LINK+ packets at $\sim 17 \mu\text{sec}$ were sent, the 10nsec average improvement in scheduling would only result in a 0.06% improvement in throughput). Furthermore, maintaining the 20 nsec resolution reduces the MAC protocol changes for c.LINK+.

Summary of the invention

A tool that can be used to improve CTC synchronization is “ranging”. Ranging is a method by which nodes measure the propagation delays to and from other nodes in the network. Ranging can also be used to improve a receiver’s AGC and burst detection performance. In addition, for orthogonal frequency division multiple access (OFDMA) schemes in which multiple packets are transmitted simultaneously, all OFDMA packets must arrive at the OFDMA receiver at roughly the same time. Otherwise, much longer cyclic prefix lengths are necessary. Ranging allows calculations to be made that allow packets to arrive simultaneously and thus reduce the cyclic prefix lengths.

Detailed Description

For MoCA networks, every node maintains a local channel time clock (CTC) counter which it synchronizes to the network coordinator’s (NC’s) CTC counter. The CTC resolution is 20 nsec for MoCA 1.x – the period of each CTC tick is referred to as a “SLOT_TIME”. In one embodiment of the disclosed method and apparatus, the internal CTC resolution is 5 nsec given the 200 MHz high-RF sampling rate (i.e. the CTC counter is incremented by 0.25 SLOT_TIMES at the 200 MHz sampling rate). This finer internal CTC resolution matches the ADC sampling rate and thus allows for more accurate time-stamping of asynchronous PHY events for the purpose of debugging.

The CTC is encoded in the MAC header which is transmitted as part of every data or link control packet (except for Beacons, in which case the CTC is transmitted as part of the MAC payload). The CTC is not transmitted in probe packets. The encoded CTC count represents the time instant that the first sample of the preamble is transmitted on the medium.

1.1 MoCA 1.x CTC Accuracy

In accordance with one embodiment of the presently disclosed method and apparatus, the NC broadcasts its CTC count in the MAC header of every MAP and Beacon packet. The NC’s CTC count represents the time instant that the first sample of the PHY preamble is transmitted on the medium. When receiving MAP packets (or any other packet from the NC), each node records the instant in time when it received the first sample of the PHY preamble using its local CTC count. The receiver then adjusts its own CTC count to synchronize it to the NC’s counter (the issue of the packet arriving at multiple times due to multipath is addressed later).

This CTC synchronization process is not perfect. The Figure 1 illustrates the CTC synchronization process.

The MoCA 1.x specification mandates that the CTC of any node shall not lag the NC’s CTC by any more than 2.2 μ sec or 110 SLOT_TIMES. The CTC time may also lead the NC by up to 0.2 μ sec in the case of -200 PPM offset. The above figure accounts for 2.1 μ sec – the remaining 0.1 μ sec can be accounted for by sampling drift due to frequency offsets (the sampling drift is up to 0.2 μ sec worst case). The following provides more details on each of the inaccuracies:

- Transmit delay: MoCA 1.x allows a transmitter to transmit a packet (including MAP) up to 400 nsec or 20 SLOT_TIMES after the CTC time reported in the packet.
→ This accounts for 0.4 μ sec of the 2.2 μ sec inaccuracy.
- Propagation delay: During the time it takes for the NC’s packet to propagate through the medium to the receiver, the NC’s CTC continues to advance. Given a mesh network with a maximum of 600ft between any two nodes and a propagation velocity of 0.65 ft/nsec or 1.54 nsec/ft, the receiver’s CTC count will lag the NC by 923 nsec or about 46 SLOT_TIMES (assuming RG-59; 0.74 ft/nsec or 1.35 nsec/ft for RG-6 and 813 nsec to travel 600 ft). For access networks, the propagation delays may be considerably larger and thus more CTC inaccuracies should be expected.
→ This accounts for about 0.9 μ sec of the 2.2 μ sec inaccuracy.
- Receive delay: MoCA 1.x does not define how to measure packet arrival time, nor does it offer an acceptable accuracy. Thus, different vendors may estimate the packet arrival time differently. Some vendors may estimate the

packet arrival time as the time of the first echo (common method for DSL). Some may use the mean arrival time (WiMAX method). Others may use the time when the power ramps to 90% of full power. Given that MoCA mesh networks expect delay spreads of up to 800 nsec¹ and have a maximum cyclic prefix length of 1.28 μ sec, it is conceivable (but unlikely) that the packet arrival time estimated by two different vendors could differ by 1.28 μ sec or 64 SLOT_TIMES. The more plausible worst case scenario is that vendors differ by 800 nsec or 40 SLOT_TIMES.
→ This accounts for about 0.8 μ sec of the 2.2 μ sec inaccuracy.

- Clock drifts between nodes: Assuming a maximum of ± 200 ppm frequency offset between any two nodes, the receiver's CTC count may drift by up to $\pm 200/1e6 \times 50e6 \text{ SLOT\_TIMES/sec} \times 1e-3 \text{ sec/MAP} = \pm 10 \text{ SLOT\_TIMES}$ per 1 msec MAP cycle.
→ This accounts for about 0.2 μ sec of the 2.2 μ sec inaccuracy.
- Implementation delays: When setting the CTC time in the MAC header, the NC must accurately estimate the delay through the PHY and analog circuitry in the transmit direction and the nodes must accurately estimate the delay through the PHY and analog circuitry in the receive direction. Any inaccuracies in these estimates (or variations due to voltage, temperature or process variations) will cause some variability in CTC times.
→ This should be negligible.
- Noise (presumably in the ability to estimate packet start time): If the receiver's estimate of the packet start time fluctuates as a function of noise or some other impairment, then the CTC time will fluctuate equally.
→ This should be negligible.
- Vendor implementation differences in estimating packet transmission time: MoCA 1.x defines packet transmission time as "when the first symbol has reached 90% of its final value". This may be interpreted differently by different vendors leading to some discrepancy.
→ Assume this is negligible.

Note that the initial 2.2 μ sec value that was used in MoCA 1.x was not obtained using the above accounting analysis but rather was measured on particular devices. Some inaccuracy existed in reaching the 2.2 μ sec value as a baseline for evaluating the changes proposed for c.LINK+. In fact, the sum of the above values is 2.3 μ sec.

The presently disclosed method and apparatus will reduce the CTC inaccuracy by ranging, defining packet transmit/receive time metrics and by tracking PPM offsets.

1.2 MoCA 1.x Packet Arrival Ambiguity

As a consequence of the 0 to 2.2 μ sec CTC time ambiguity between nodes, the slop in transmit time and the fact that the channel propagation delay is unknown, the packet arrival time at the receiver has some ambiguity. The Figure 2 illustrates this ambiguity.

As noted in Figure 2, the impact of the packet transmission time variability requires an extra 2.6 μ sec in inter-frame gap (IFG). In addition, the packet arrival time will have -2.2 to $+3.5$ μ sec of unpredictability. This ambiguity in packet arrival time is based on a strict interpretation of the MoCA 1.x standard and may be pessimistic in terms of how early a packet can arrive (the -2.2 μ sec term which occurs when Err₁ is 0, Err₂ is 2.2 μ sec and the propagation time is 0). For example, if Err₁ is 0, then presumably Node 1 is close to the NC and if Err₂ is 2.2 μ sec, then presumably Node 2 is far from the NC – thus, Nodes 1 and 2 cannot be co-located and the propagation time between Nodes 1 and 2 cannot be 0 and is more likely 0.9 μ sec. This being the case, the packet can arrive at most 1.3 μ sec early. Regardless, the presently disclosed method and apparatus will reduce the packet arrival ambiguity by reducing the CTC inaccuracy and by ranging.

The Figure 3 illustrates the true inter-frame gap for one particular node. The local CTC_{Start} and CTC_{End} times indicate the expected start and end times for that node (as computed from the MAP); the hash marks indicate the variability around those

¹ The definition of delay spread in the MoCA 1.0 spec is ambiguous.

start and end times; a -1.3 to $+3.5$ μsec packet arrival ambiguity is assumed. It should be noted that these IFG times are optimistic in that the duration of received packets will be longer by the delay spread of the channel (i.e. if the delay spread between the node and the NC is 800 nsec, the node's CTC may be 800 nsec late; if the delay from that node to another node is also 800 nsec, then the end of that packet to the other node will be extended by another 800 nsec).

This "true" inter-frame gap indicates the amount of time the node has after processing a first packet to prepare for the next packet. The true inter-frame gap can be defined in one of the two following ways. Either:

- The node prepares for a next packet in the 'guaranteed' quiet portion of the IFG which is 3.5 μsec after CTC_{End} or equivalently $\text{IFG} - 4.8$ μsec before $\text{CTC}_{\text{Start}}$. This is the easiest method because the CTC_{End} is known well in advance. The worst case true inter-frame gap could be as small as $\text{IFG} - 4.8$ μsec (ignoring delay spread).
- The node prepares for a next packet immediately after the previous packet finishes (i.e. up to 1.3 μsec before its expected CTC_{End} time). In this case, the true inter-frame gap could be as small as $\text{IFG} - 3.5$ μsec .

One particular embodiment of the disclosed method and apparatus prepares for the next packet based on the Local $\text{CTC}_{\text{Start}}$ time (at least for the AFE/RF preparations; SoC (system on a chip) preparations can begin at any time after the previous packet). For MoCA 1.x packets with 10 μsec IFG, this implies that the AFE/RF can begin preparations up to 6.5 μsec before the expected start time – the next packet may then start as early as 1.3 μsec before the expected start time. In one embodiment, ranging is performed and thus the packet start time is known.

1.3 CTC Synchronization and Ranging

Propagation delay is the largest source of inaccuracy in CTC synchronization and packet arrival time. In some embodiments ranging enables tight control on packet transmission time by accounting for propagation delays. As noted in previous sections, ranging results in a reduced IFG requirement, more predictable packet arrival times and a reduced cyclic prefix length for OFDMA.

The method by which packets are 'released' onto the medium dictates how the ranging information is utilized. One particular embodiment defines three transmit scenarios: one-to-many 'broadcast' packets, many-to-one 'OFDMA' packets and one-to-one 'unicast' packets. Given that all nodes are synchronized to the NC, the packet transmission time for each is defined as follows:

- Broadcast packets: Nodes start transmission at the scheduled CTC time. Packets arrive at each node at different times according to the propagation delays – if the receiver knows what the propagation delay is, it can estimate when the packet will arrive.
→ i.e. fixed transmit time; variable receive time
- OFDMA packets: Each node adjusts transmission time by $D_{\text{max}} - \text{delay\_to\_receiver}$ such that each packet arrives at the receiver at the scheduled CTC time plus D_{max} regardless of which transmitter is sending the packet. D_{max} represents the worst case propagation delay expected for that particular deployment model (i.e. 923 nsec for MoCA mesh networks).
→ i.e. variable transmit time; fixed receive time
- Unicast packets: Either of the two previous methods may be used with equivalent performance benefits. For MoCA 1.x, the first method is used.
→ I prefer the first method for unicast packets (fixed transmit time; variable receive time) because (a) that is the mode required to receive MoCA 1.x unicast packets and thus minimizes the differences in how unicast packets are received², (b) it makes it a slight bit less obvious that the receiver can still use the delay information to predict exact

² In fact, while a node operating in accordance with one protocol may not be able to range with a device operating in accordance with another, it can still measure the variability in packet arrival time from a MoCA 1.x device and attempt to

packet arrival time which will benefit AGC and burst detect, (c) it makes the packet transmit times on the wire consistent before and after ranging has been performed (the only exception is the first Admission Request packet) and (d) eliminates the need for signaling delays between non-NC nodes.

There are many methods of ranging. A trivial open-loop method relies on measuring the path loss between the two nodes to infer the propagation time. However, because of the nature of the MoCA coaxial cable plant, and in particular, the way that the signal bleeds across splitter ports and the different types of cable, path loss is a poor indicator of propagation time. As a consequence, a closed-loop method is required.

A simple closed loop method measures the round-trip delay of a signal and assuming channel reciprocity, assumes the one way propagation time is half of the round trip propagation time. This is the underlying method applied here; however, the assumption of channel reciprocity (i.e. that the propagation delay in one direction is equal to the propagation delay in the opposite direction) is not assumed. While I expect that the actual cable plant would exhibit reciprocity, the transmit and receive paths of the analog circuitry are different and thus may cause differences in propagation delay. In addition, due to vendor differences in estimating the packet arrival time, the propagation delay estimate may be different depending on which vendor is making the measurement (i.e. the 0 to 400nsec transmit time variability and 0 to 800nsec receive time variability are examples).

CTC synchronization and ranging consists of the following three components:

- A new node performs synchronization and ranging to the NC as part of admission to a c.LINK+ network. This measures the propagation delay between the new node and the NC as well as synchronizes the new nodes CTC count to the NC's CTC count.
- A new node performs ranging to the other nodes as part of admission to a c.LINK+ network. This assumes that the new node has completed CTC synchronization and ranging with the NC. For access networks, this component is unnecessary as the network has a star topology.
- Periodic maintenance to track slow changes in propagation delays. This is performed in conjunction with EVM maintenance and is performed between all nodes in the network including the NC (if a mesh network; otherwise just with the NC).

These components are detailed in the following sections.

1.3.1 Synchronization and Ranging to the NC

The following diagram illustrates the sequence of operations that a new node must follow in measuring the propagation delay between itself and the NC as well to synchronize its CTC count. This diagram is more conceptual in nature – the actual mechanics of starting packet transmission at the correct instant as well as estimating the packet arrival time at the receiver are described in a following section. Furthermore, any CTC drift due to frequency offsets are assumed zero here but are addressed later.

In this diagram, the following conventions are used: CTC_k represents the scheduled CTC time for the k-th packet; Err_n is the relative error of the n-th node's local CTC to the NC's CTC (thus, $Err_0 = 0$ by definition given that the NC is node 0); D_{nm} is the actual propagation delay between the n-th node and the m-th node; and, d_m is the propagation delay estimated by the n-th node to/from the m-th node. CTC synchronization and ranging is complete after reception of the Admission Response packet; the other packets illustrate the various usage cases.

predict the arrival time. While it may not be nearly as accurate as for c.LINK+, it may be sufficient to gain some AGC and burst detection performance benefits.

-- 6--

Ranging for the new node to NC case is summarized as follows:

- New node sets its local CTC counter to the Beacon's reported CTC count. It assumes the propagation delay to the NC d_0 is zero. It subsequently transmits the Admission Request packet at the scheduled time (as indicated in the Beacon).
- The NC receives the Admission Request packet zero to $2 \times 923 = 1846$ nsec after its expected time. It assumes the propagation delay to the new node d_1 is half the delay between the expected and actual packet arrival time. It subsequently sets the delay value $d = d_1$ in the Admission Response packet and transmits the Admission Response to the new node at the scheduled CTC time.
- The new node, upon receiving the Admission Response, reads the NC-specified delay and (a) sets its d_0 to this value and (b) adds this value to its local CTC time.

Upon completion of this ranging and synchronization operation, the CTC time of Node 1 will lag the NC's CTC time by exactly $(D_{01} - D_{10})/2$. If the channel is reciprocal, then this error will be zero. Note that regardless of channel reciprocity, the packets will always arrive at the NC or Node 1 exactly when that node expects it – this is illustrated in Figure 5. Of course, the packet transmission time on the wire will be off by Err_1 at Node 1.

Besides performing the functions identified in the diagram, the estimated delay d_1 must be transmitted in the payload of the Admission Response packet. Support for this field must be provided in the c.LINK+ MAC protocol messages. Given that the maximum propagation delay for mesh networks is 46 SLOT_TIMES and likely no more than 255 SLOT_TIMES for access networks (i.e. maximum delay of 5.12 μsec or 3,328 ft for RG-59 and 3,789 ft for RG-6); an unsigned 8-bit field should suffice.

Once a node has been admitted to the network, it must periodically update the ranging and synchronization information to accommodate slow channel variations (or can average to remove estimation jitter). Figure 6 illustrates the sequence of operations that a node must follow in tracking the propagation delay between itself and the NC as well to maintain CTC synchronization. Note that even though the first packet is the EVM packet, this maintenance process is actually only performed once per EVM session – which is appropriate given that EVM and ranging are both channel related.

This is very similar to the initial acquisition method; however, the messages are different. Again, after this is completed, the packet arrival times at either the NC or the node will be exactly as expected. Note that no gross adjustments (i.e. beyond just tracking out frequency offsets) shall be done after the gross adjustment of the MAP and the transmission of the EVM Probe. The MAC protocol shall provide a field in the EVM Probe Response for relaying the residual delay measurement – this will be a signed value and again 8 bits will suffice (i.e. ± 128 SLOT_TIMES).

As a final comment, it would be acceptable to perform ranging as part of the EVM function only rather than on both the EVM and the initial Beacon. This would further minimize the changes to the MAC protocol in that only the EVM Probe Response would require a delay field. However, in this case, it would be beneficial to increase the delay field from 8 bits to 12 bits to account for the larger initial delay value. Figure 7 is a sequence diagram for this initial “node to NC” ranging (i.e. it is identical to that process shown in **Error! Reference source not found.** but performed on the very first EVM session between the NC and the new node).

1.3.2 Ranging to non-NC Nodes

Once a new node has completed admission to the network and has synchronized and ranged with the NC, it must perform ranging with all other nodes in the network. The purpose of this is to (a) enable ranging to carry forward in the case of NC hand-off and (b) enable receivers to predict packet arrival time to improve AGC and burst detection functions. The method

of ranging is illustrated in Figure 8 (again, somewhat conceptual – the frequency drift and packet transmit/receive estimation mechanism are not considered here).

Note that this ranging requires no signaling between the two nodes. While the ranging estimates may not be perfectly accurate, the packets will arrive exactly when expected. The nodes shall update the ranging estimates at least once every EVM probe session (optionally also on EVM reports as shown above or on any other data packets). This periodic updating is to account for slow drifts in each node's CTC time as well as possible changes in propagation delay due.

Note that the delays d_1 and d_2 computed in **Error! Reference source not found.** are not equal and thus if exchanged between nodes, could provide some additional information. One possibility is that if all nodes know the measurements of all other nodes, that perhaps the CTC error between each node and the NC can be further minimized. This minimization helps achieve a lower IFG but will not impact the receiver's ability to determine when the packet will arrive – as this is already known perfectly.

Consider the three node network shown below. Here, D_{nm} is defined as the sum the Node n TX_n delay, a channel delay Ch_{nm} and a Node m RX_m delay. It is assumed that TX_n is constant regardless of which node is being transmitted to, RX_m is constant regardless of which node is being received from and Ch_{nm} has reciprocal delay (i.e. $Ch_{nm} = Cn_{mn}$). Figure 8 illustrates all the knowns.

From Figure 9, the equations in terms of TX, Ch and RX delays are

$$\begin{aligned} d_0^{(1)} &= TX_0 + TX_1 + 2Ch_{01} + RX_0 + RX_1 \\ d_0^{(2)} &= TX_0 + TX_2 + 2Ch_{02} + RX_0 + RX_2 \\ d_2^{(1)} &= TX_1 + Ch_{12} + RX_2 \\ d_1^{(2)} &= TX_2 + Ch_{12} + RX_1 \end{aligned}$$

In this case, there are 4 equations and 9 unknowns – thus, no solution exists. Of course, what are of concern are the CTC errors Err_n . Writing the equations in terms of the errors leads to

$$\begin{aligned} d_0^{(1)} &= Err_1 + D_{10} \\ d_0^{(2)} &= Err_2 + D_{20} \\ d_2^{(1)} &= D_{21} - Err_1 + Err_2 \\ d_1^{(2)} &= D_{12} + Err_1 - Err_2 \end{aligned}$$

Here, we have 4 equations and 6 unknowns – still not enough to provide a solution. Given that no quick and obvious solution exists for using the full delay information between all nodes to reduce the CTC errors, a full exchange of delay information between nodes is not proposed.

1.4 Packet Transmission and Arrival Times

A node synchronizes its CTC time to that of the NC by comparing the local receive time of a Beacon or MAP packet to the NC's CTC transmit time as indicated in the payload of that packet. To ensure accuracy, the NC must accurately measure the transmit time and the receiver must accurately measure the receive time. The following requirements are defined:

- For a given channel, a node must consistently compute the same transmit and arrival times. For example, if the channel has two roughly equal echo paths, the arrival time does not fluctuate depending on which path happens to be stronger. Any such fluctuations cause CTC jitter.
- All nodes, regardless of vendor, must use a consistent metric for measuring transmit and arrival times. For example, if given the same channel two different vendors compute different packet arrival times, then the CTC times will not be synchronized between the nodes.

The packet transmission and arrival times should be computed at the interface to the transmission medium (i.e. F-connector). Between the TX and RX medium interfaces, the channel delay should be reciprocal; however, the propagation time through the analog paths in the transmitter and receiver may be different. In addition, differences in algorithms used to compute packet transmission and arrival times may differ causing differences in measurement.

Unfortunately, the MoCA 1.x specification's metric for measuring the transmit time is ambiguous and it does not define a metric for measuring arrival times. The MoCA 1.x spec defines the following:

[Section 3.13.2] In order to avoid collisions in a MoCA network, all nodes MUST:

Transmit packets such that the first symbol of the preamble appears at its RF connector no more than Tx_delay after the transmit time specified in the MAP is reached on the local time reference. The transmit time of the first symbol is measured as when the first symbol has reached 90% of its final value. Where Tx_delay = 400 nsec.

[Section 3.3.6 – Beacon Format]

System clock when Beacon transmission begins on the medium (beginning of preamble).

[Section A.1.1 – Transmit Clock (in all packet headers, except Beacons)]

This field contains the value of system clock when the first bit of the PHY packet (beginning of preamble) is transmitted on the medium.

This is ambiguous in several ways. The first is the statement 'first bit of the PHY packet' – it should be the first sample. Secondly, the Beacon Format and Transmit Clock sections make no reference to the 90% metric. Third, the 90% metric applies to when a packet is transmitted relative to the CTC time and not how to measure the transmission time. Fourth, the 90% metric does not state if it is 90% of the peak amplitude, 90% of the peak power or 90% of the total power. Finally, the definition of 'first symbol' is misused – 'symbols' are OFDM symbols of which the CE symbols are the first; the short sequence consists of segments and each segment consists of samples (note that if the preamble segments are considered symbols, a common mix-up, then even more ambiguity may be introduced).

1.4.1 Accurate Reporting of Packet Transmission Time

Each node in the network must report its transmission time as part of each packet's payload. This transmission time is used by each receiving node to calibrate their local CTC counter to the NC's CTC counter and is indirectly used to perform ranging. Consistency from packet to packet is mandatory. Consistency between vendors is strongly desired to ensure smooth NC handoffs.

Several methods for defining the packet transmission time are illustrated in the following figure. The top plot shows an example transmitter impulse response and the bottom plot shows the corresponding power (blue) and integrated power (pink). Time zero represents the time instant that the first sample of the preamble is inserted into the Jaws interpolator. The impulse response is measured between the interpolator input and the transmitter's interface to the transmission medium.

From Figure 10, the following measurement points are reasonable candidates (note the 90% threshold is arbitrary and can be replaced with any other threshold):

- 90% of the peak amplitude of the RF signal envelope. This is the typical ‘ramp-up time’ definition.
- 90% of the peak power. This is very similar to and would likely provide similar results as the 90% peak amplitude threshold.
- 90% of the total power. This is a straightforward computation but may be inaccurate due to the typical flatness as it approaches the P_{total} value.
- The mean delay of the sample. This is effectively the ‘group delay’ of the transmitter. It would likely be the most stable measurement. This could be seen as a departure from MoCA 1.x given that it has no 90% component.

While several of the above methods are acceptable, the mean delay method is proposed for c.LINK+. It matches the receiver’s definition of packet arrival time.

1.4.2 Accurate Measurement of Packet Arrival Time

Each node in the network must measure the packet arrival time. This packet arrival time is used by each node to calibrate their local CTC counter to the NC’s CTC counter (by observing the difference between the reported packet transmission time and the measured receive time) and is indirectly used to perform ranging. Consistency from packet to packet as well as between vendors is mandatory to ensure proper synchronization.

Several methods for defining the packet arrival time are illustrated in the following figure. The plot shows an example receiver power delay profile – this is obtained from the echo profile probing mechanism. Time zero represents the time instant that the first sample of the preamble arrives at the RF connector. The impulse response is measured between the transmitter’s interpolator input and the receiver’s decimator output.

From Figure 11, the following measurement points are all reasonable candidates³ (note the 90% threshold is arbitrary and can be replaced with any other threshold):

- 90% of the peak power (or amplitude) of the signal. This is the typical ‘ramp-up time’ definition. This could be a difficult determination if there are two roughly equal peaks such that sometimes one peak is selected vs. the other.
- 90% of the total power. This is a straightforward computation but may be inaccurate due to the typical flatness as it approaches the P_{total} value.
- The mean delay of the sample. This is effectively the ‘group delay’ of the channel. It would likely be the most stable measurement. This could be seen as a departure from MoCA 1.x given that it has no 90% component.
- The CP start or CP end. This would be a function then of the receiver’s tolerance to ISI which may be a function of the average receive level.
- The first path. This could be hard to determine accurately if the peak is relatively flat.

While several of the above methods are acceptable, the mean delay method is proposed for c.LINK+. It is extremely stable – other methods may behave poorly in some channels (i.e. particularly the 90% of peak if there are two nearly equal peaks or 90% of power if the integrated power measurement is roughly flat in the 90% region).

1.5 CTC Synchronization and Tracking

Note that while ranging fully accounts for all CTC offsets at the time when ranging is performed, the CTC clocks of the NC and nodes will drift due to the clock offsets of up to ± 200 ppm. Note that the MoCA 1.0 simply states that the CTC inaccuracy shall be between 0 and 2.2 μsec – thus, the CTC time may drift anywhere between these two extremes (albeit, I expect the practical limit is ± 200 nsec which assumes the nodes update their CTC time every 1msec MAP cycle). This would seriously negate the benefits of ranging. Therefore, Jaws shall apply CTC tracking and periodic updates to ensure that the CTC clocks between any two nodes does not drift significantly.

³ This accounts for 800 nsec of the 2.2 μsec CTC inaccuracy as specified in the MoCA 1.x spec.

CTC tracking at a node involves updating the CTC clock each MAP cycle to match the NC's reported CTC clock and secondly, to use the estimated clock offset (ppm estimate) to more accurately increment the node's CTC clock between MAP updates (i.e. rather than incrementing the CTC clock in steps of 1, it would increment the CTC clock in steps of 1 minus the ppm offset). For CTC tracking, assume tracking to 2 ppm (the receiver tracks to better than 0.2ppm), this corresponds to 1/20-th of a single SLOT_TIME (2 nsec) per 1 msec MAP cycle. With this accuracy, the CTC clocks will always be perfectly synchronized. There still may be some timing jitter due to burst detection variations – these and other jitters can be mitigated if a slow tracking loop is applied.

Note that during ranging maintenance, gross CTC updates based on the MAP shall be suspended after receiving the MAP and before transmitting the EVM Probe to ensure that the ranging estimate is not skewed.

1.6 NC Handoff and Failover

Due to reasons beyond the scope of this document, it may be necessary at times to handoff the NC functions from the current NC to another node in the network (or a controlled switch to the backup NC is performed due to an NC failure). In this case, a seamless CTC synchronization and ranging handoff is desired such that the shorter IFG can be maintained and OFDMA can still be used. The NC handoff is signaled in the Beacon and thus the new node as well as all other nodes will be aware of the NC handoff.

In order to ensure this seamless handoff, all nodes shall record the delays between themselves and all other nodes in the network (i.e. each node must store N-1 delays in an N node network). This is accomplished using the EVM's as defined in Section 1.3.2. Given that these delays are required for OFDMA packet transmission to the NC, upon an NC handoff, the nodes shall use the delays measured for the new NC.

In addition, the new NC will have some CTC offset relative to the old NC and to all other nodes in the network. At the time of the handoff, all nodes will already have their CTC's synchronized and all nodes will have estimates of the frequency offsets between themselves and all other nodes. Thus, the only remaining task of the new NC is to migrate the network to its own CTC time (i.e. and not to the old NC's CTC time) by migrating the frequency estimation factor that it used to track the old NC's CTC time to zero. To ensure a gradual CTC transition, the frequency estimation factor shall be reduced to zero gradually and by no more than 2 PPM (1/20-th of a single SLOT_TIME) per MAP cycle.

1.7 c.LINK+ CTC Synchronization and Ranging Requirements

The performance requirements for CTC synchronization and ranging are defined here.

CTC error for node n is $Err_n = (D_{0n} - D_{n0})/2$. Writing this in its constituent parts, $Err_n = (TX_0 + RX_0 - TX_n - RX_n)/2$. The packet transmission time TX shall be accurate to within 0 to 60 nsec. The packet arrival time shall be accurate to within 0 to 100 nsec (assuming TX is perfect). Thus, Err_n shall not lag the NC's CTC by any more than 80 nsec worst case. The CTC drift due to frequency offset shall be limited to 20 nsec per MAP cycle – the CTC shall be updated every MAP cycle and shall be incremented between MAP cycles accounting for the frequency drift. Thus, the CTC of any c.LINK+ nodes shall not lag the NC's CTC by any more than -20 to +100 nsec. It should not be assumed that these CTC inaccuracies are fixed constants – the total CTC inaccuracy may fluctuate within this -20 to +100 nsec range on a per-MAP basis.

Figure 12 illustrates the impact of the CTC and packet arrival time variability for c.LINK+. In this case, the effect of delay spread is shown (although not accounted for in the numbers) for received packets. The delay spread accounts for the amount of time after the mean packet arrival time of the channel that echoes continue to arrive. This time needs to be accounted for in the IFG for the purposes of avoiding channel collisions but does not impact the amount of time the receiver has after a first packet to prepare for the next packet. The maximum delay spread is 800 nsec (furthest distance between any two echo paths).

The ranging accuracy is dictated solely by the accuracy of the CTC; yet, the method of ranging implies that packets will always arrive at the node of interest exactly when expected. Thus, the propagation delay estimation error shall be assumed negligible.

The IFG must therefore account for 0.9 μsec of propagation delay, 0.1 μsec of CTC inaccuracy, 0.06 μsec of packet transmission time uncertainty and finally 0.8 μsec of delay spread – for a total of about 2 μsec . Given a 5 μsec IFG, the minimum time a node has after processing one packet and before the next packet starts is about 4 μsec (RX to RX or RX to TX cases).

1.8 Secondary Benefits of Ranging

The primary benefits of ranging are to reduce the IFG by more tightly constraining the packet transmission times and to more tightly constrain packet arrival times to optimize the CP lengths for OFDMA. The following additional benefits are expected – these benefits are due exclusively to the fact that the receiver will know very accurately when a packet will arrive.

- Receiver analog components will have more settling time (IFG minus 2 μsec).
- AGC can ensure that it does not track on pre-packet noise or interference.
- Burst detector can significantly reduce the search window time (e.g. to ± 10 samples) virtually eliminating false or missed detection. This is key to the new c.LINK+ high-throughput unicast preamble which does not transmit a long sequence but rather uses just a portion of the channel estimation symbols for burst detection.
- For OFDMA, can limit or eliminate burst detection (good given that OFDMA preambles are a blend from multiple transmitters).

1.9 Cable Assumptions

The following table lists the coaxial cable assumptions used in this document. The Velocity Factor (VF) is the ratio of the signal propagation speed relative to the speed of light and is used to compute the velocity of propagation in ns/ft.

Table 1: Coaxial cable characteristics

Cable	Propagation		dB Loss/100ft vs. Frequency (MHz) into 75 Ω									
	VF	ns/ft	1.0	10	50	100	200	400	900	1000	3000	5000
RG-6	.75	1.35	.26	.83	1.9	2.7	4.1	5.9	6.5	9.8	23.0	32.0
RG-59	.66	1.54	.33	1.1	2.4	3.4	4.9	7.0	11.0	12.0	26.5	42.0

Maintenance and calibration are not required.

Electronic Patent Application Fee Transmittal				
Application Number:				
Filing Date:				
Title of Invention:		Method and apparatus using of range estimates to improve efficiency in a home entertainment network over coaxial cable		
First Named Inventor/Applicant Name:		Arndt J. MUELLER		
Filer:		Bruce Wayne Greenhaus/Tim Ellis		
Attorney Docket Number:		E090002USP1		
Filed as Large Entity				
Provisional Filing Fees				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
Provisional application filing	1005	1	220	220
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Miscellaneous:				
Total in USD (\$)				220

Electronic Acknowledgement Receipt	
EFS ID:	4615303
Application Number:	61144676
International Application Number:	
Confirmation Number:	3694
Title of Invention:	Method and apparatus using of range estimates to improve efficiency in a home entertainment network over coaxial cable
First Named Inventor/Applicant Name:	Arndt J. MUELLER
Customer Number:	77330
Filer:	Bruce Wayne Greenhaus/Tim Ellis
Filer Authorized By:	Bruce Wayne Greenhaus
Attorney Docket Number:	E090002USP1
Receipt Date:	14-JAN-2009
Filing Date:	
Time Stamp:	19:02:06
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	\$220
RAM confirmation Number	4161
Deposit Account	504613
Authorized User	
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)	

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		E090002USP1_AppAsFiled_1-14-09.pdf	4409284 be2ce89ba42e3f0e88db53f514af0636d0744dc6	yes	25
	Multipart Description/PDF files in .zip description				
	Document Description	Start	End		
	Application Data Sheet	1	4		
	Provisional Cover Sheet (SB16)	5	5		
	Specification	6	16		
	Drawings-only black and white line drawings	17	25		
Warnings:					
Information:					
2	Fee Worksheet (PTO-06)	fee-info.pdf	29625 904a1c633fcb5bcd591b1316bd045fac2bd32e	no	2
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Information:					
Total Files Size (in bytes):			4438909		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					

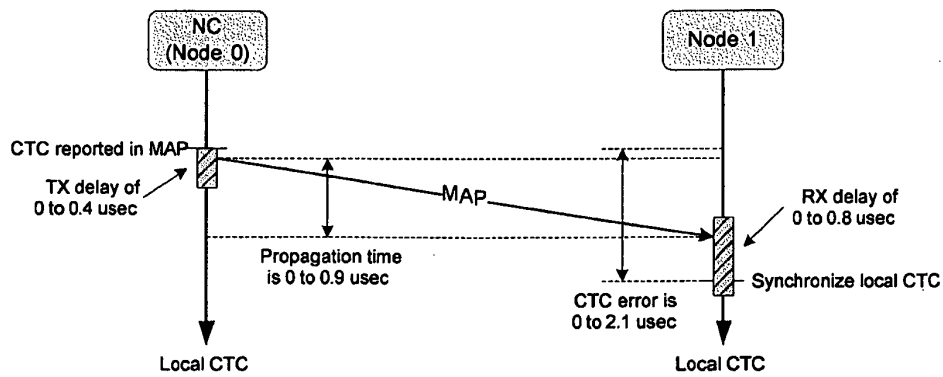


Figure 1: MoCA 1.x CTC synchronization methodology

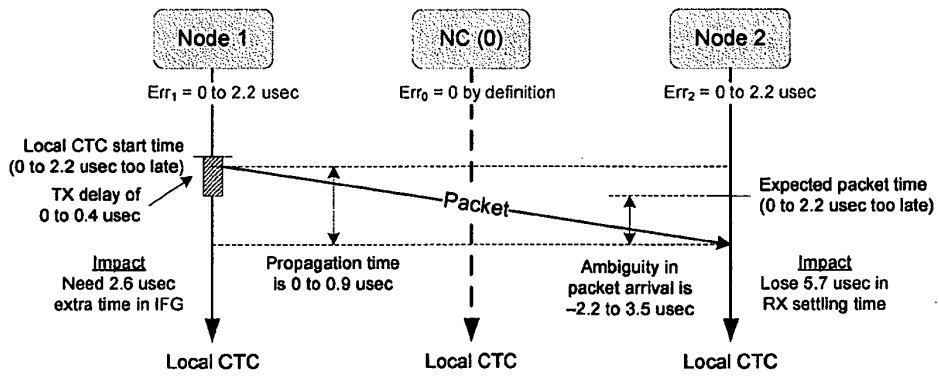


Figure 2: Variability of packet arrival time for MoCA 1.x.

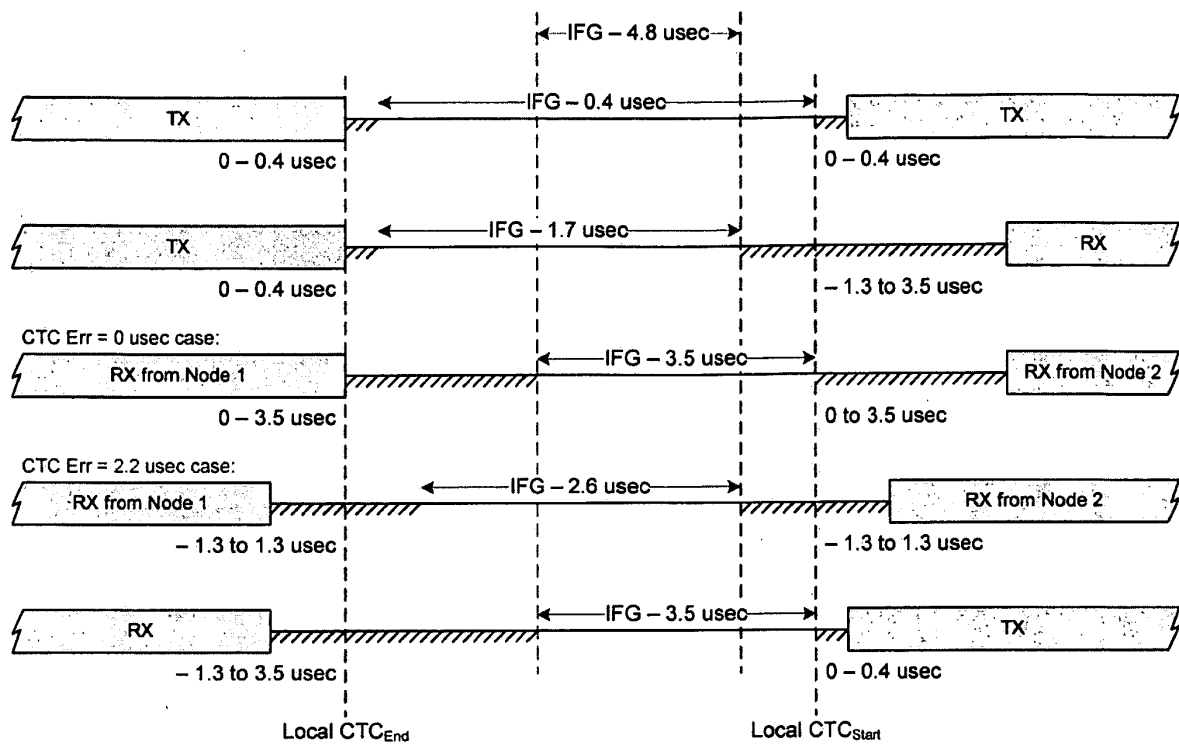


Figure 3: Impact of CTC and packet arrival time variability on true inter-frame gaps.

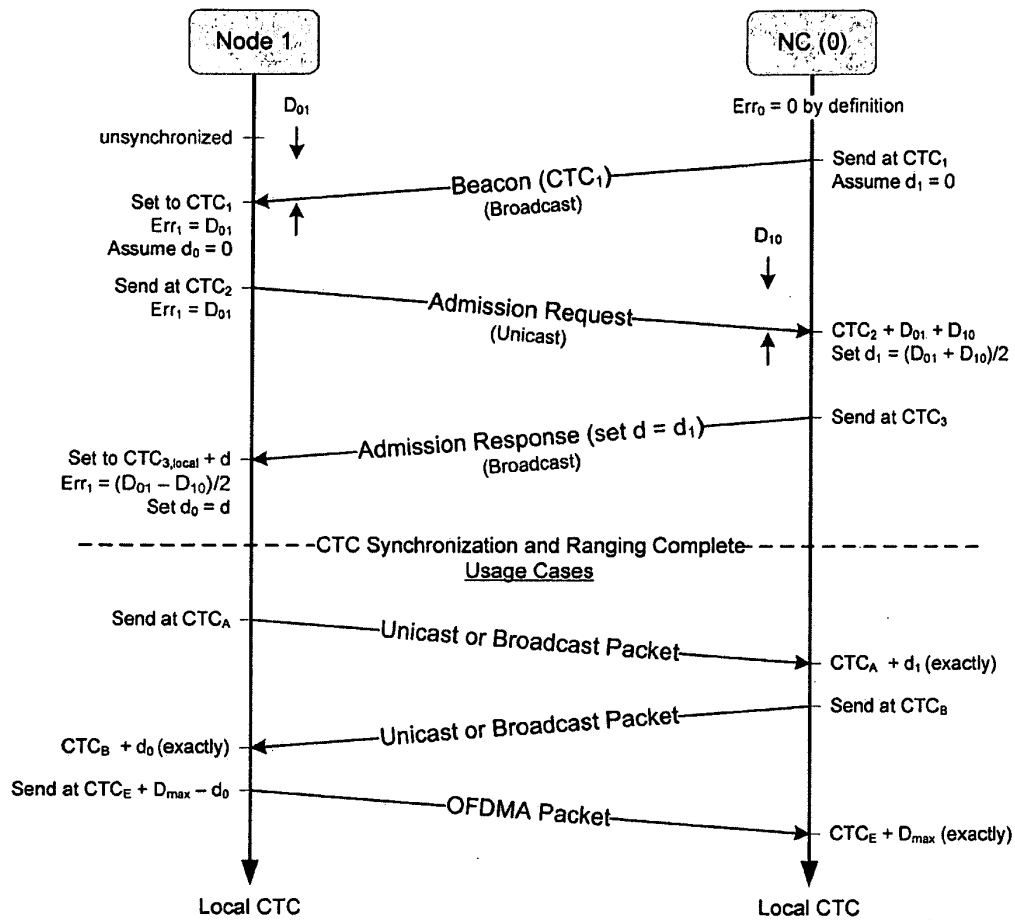


Figure 4: Sequence diagram for “new node to NC” synchronization and ranging – Beacon method.

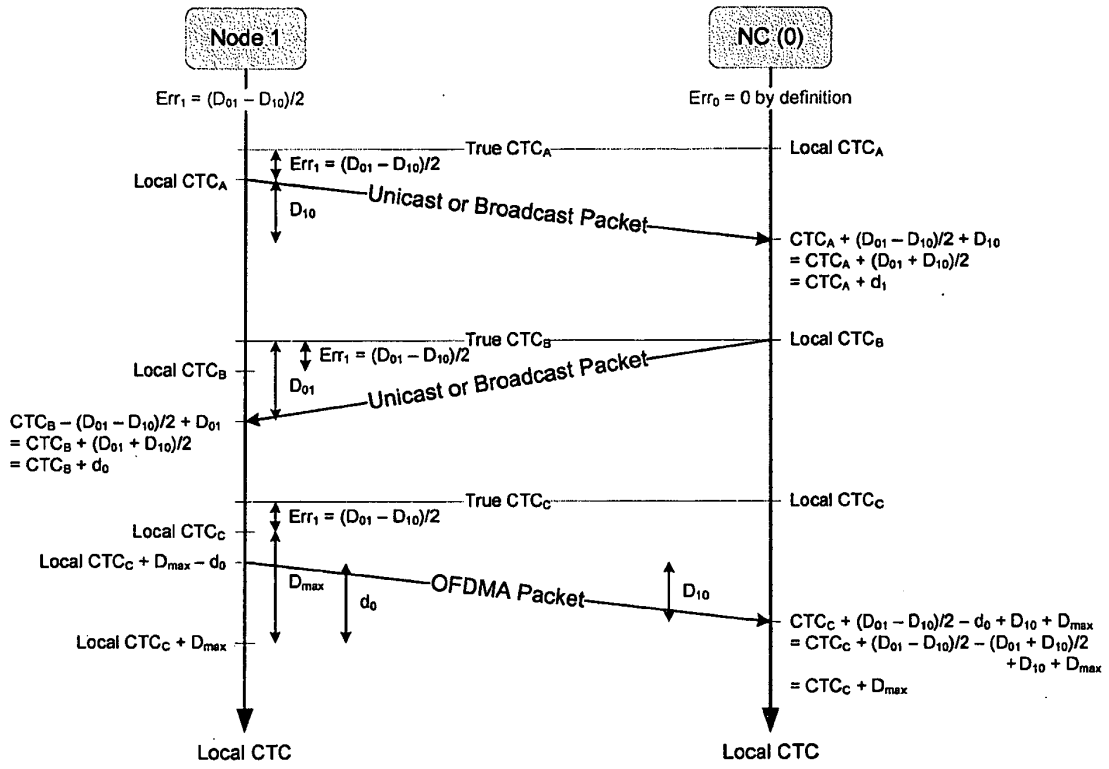


Figure 5: Proof that packets will arrive at the NC and Node 1 exactly when expected.

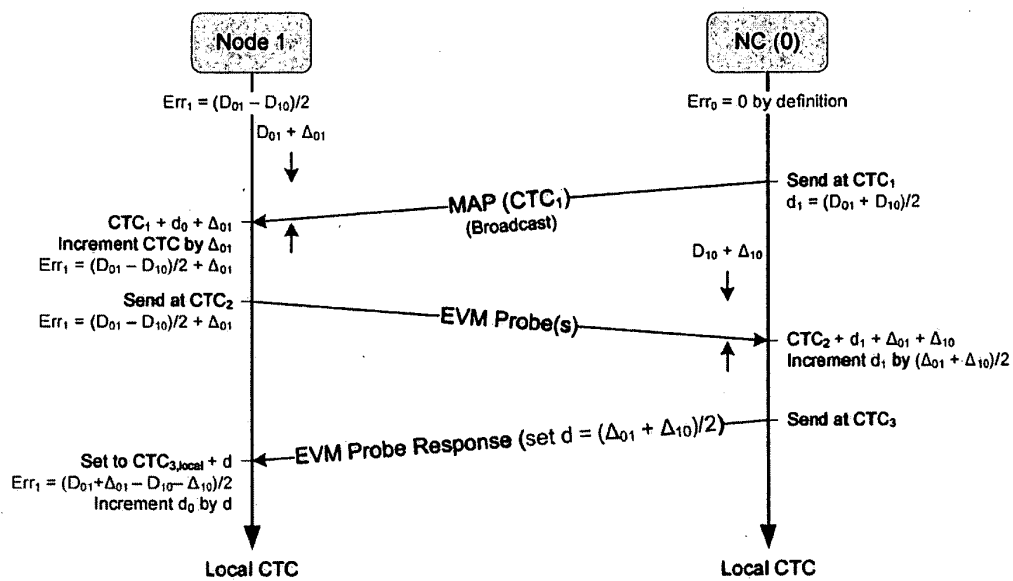


Figure 6: Sequence diagram for “node to NC” synchronization and ranging maintenance.

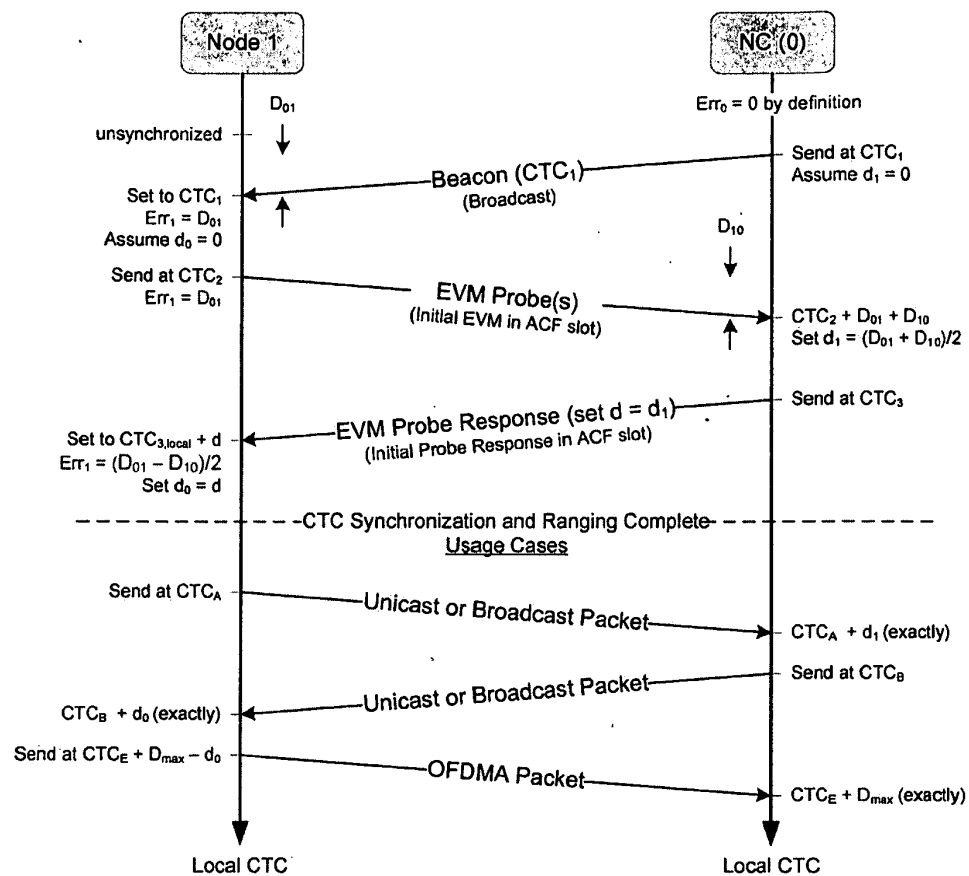


Figure 7: Sequence diagram for “new node to NC” synchronization and ranging – EVM method.

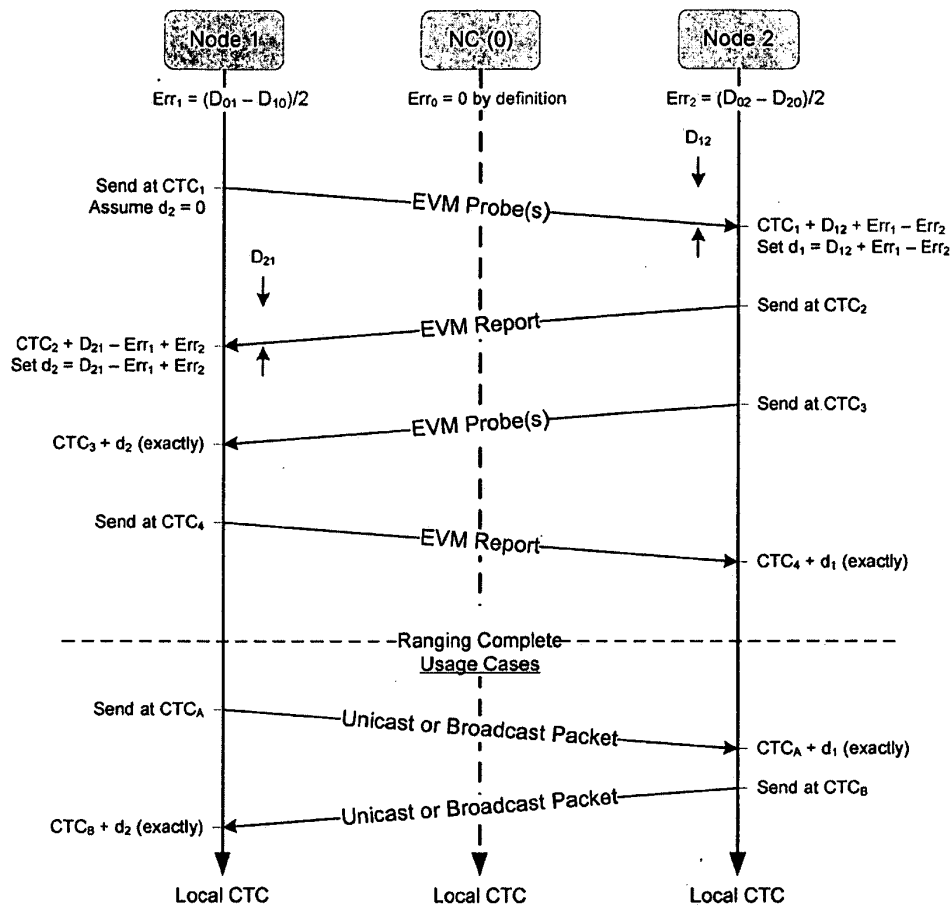
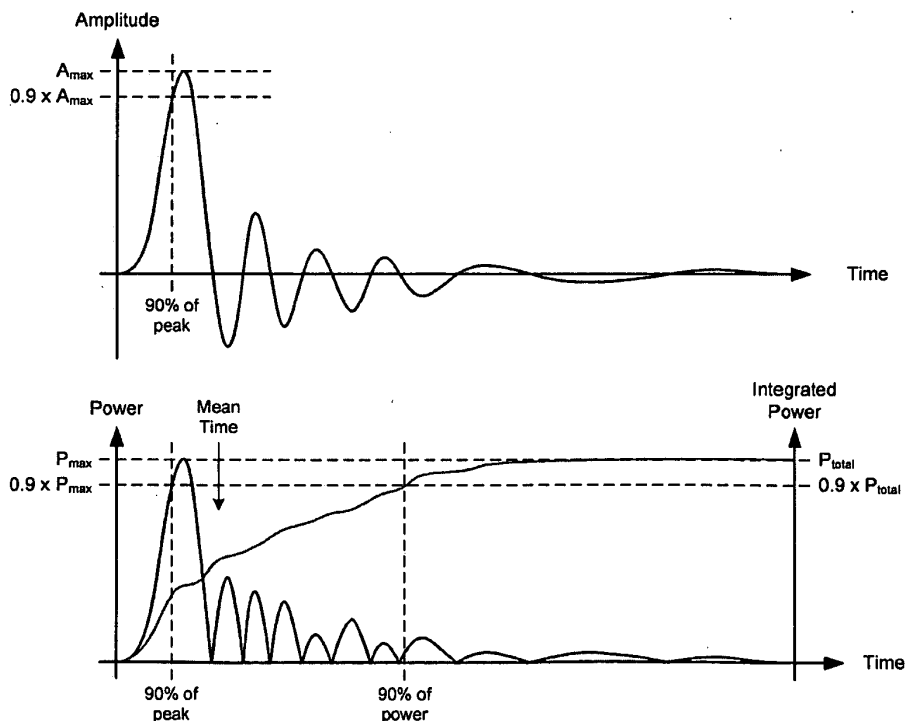
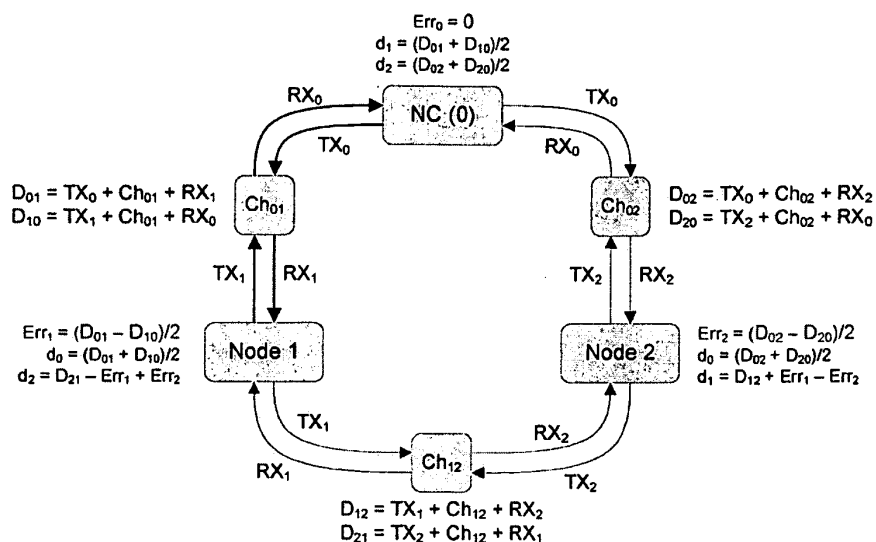


Figure 8: Sequence diagram for "new node to existing node" ranging.



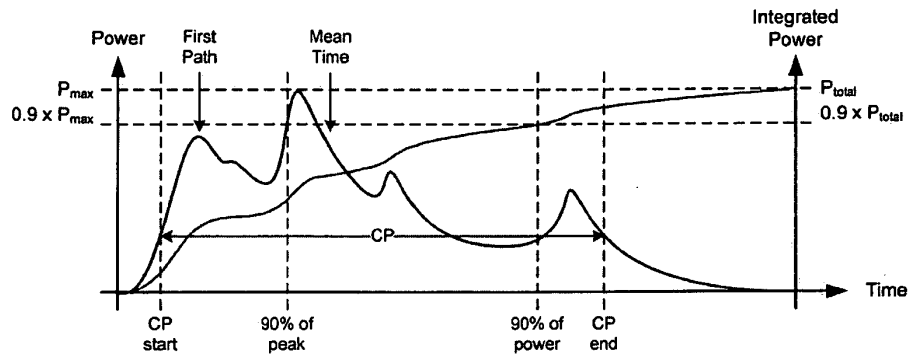


Figure 11: Example receive impulse response – illustrates points for measuring packet arrival time.

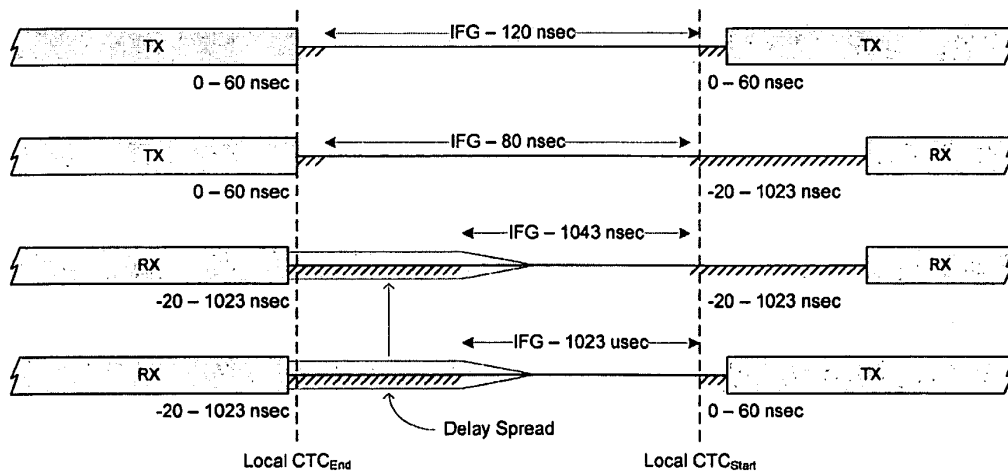


Figure 12: Impact of CTC and packet arrival time variability on true inter-frame gaps.