617 Arcadia Terrace #303, Sunnyvale CA 94085 (US).
KATSURASHIMA, Akira; 16-1 Yurigaoka 3 Tyome,
Natorishi, Miyagiken (JP).

(54) Title: METHOD AND SYSTEM FOR DETERMINING MOBILE UNIT LOCATION BY AGGREGATION OF TAGGED
SIGNALS FROM A DISTRIBUTED ANTENNA SYSTEM
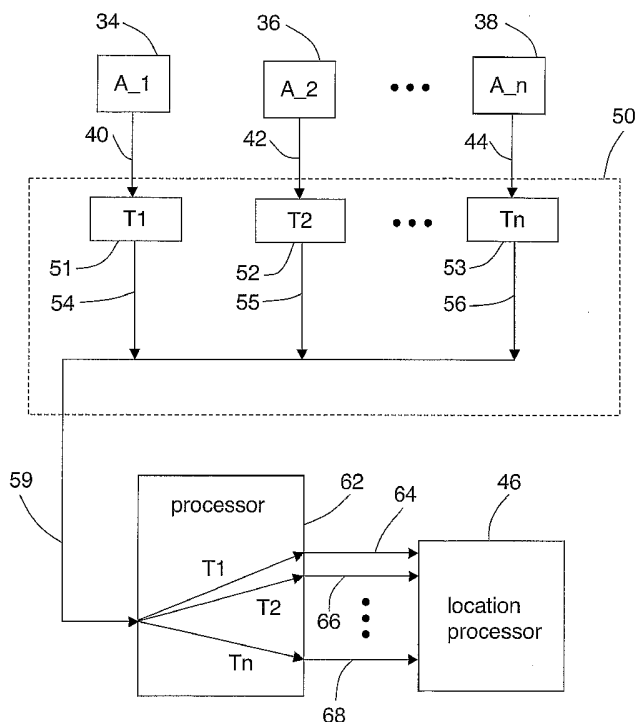
(57) Abstract: A method for determining
the location of a mobile unit tags uplink
signals received at separate antennas with
corresponding antenna tags. All of the
uplink signals are combined into a single
combined signal, which may be transmitted
to a base station. One or more signal parts
are selected from the combined signal,
and these selected parts are decoded to
determine their corresponding antenna
tags. A location algorithm is applied to the
decoded signal parts to determine a location
of the mobile unit.

ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHOD AND SYSTEM FOR DETERMINING MOBILE UNIT LOCATION BY

AGGREGATION OF TAGGED SIGNALS FROM A DISTRIBUTED ANTENNA

SYSTEM

FIELD OF THE INVENTION

This invention relates to methods and systems for
location determination of a mobile wireless unit.

BACKGROUND

Fig. 1 is a side view of a building **10** having a typical
wireless communication infrastructure including antennas **12**,
links **14**, remote units **16**, a backbone connection **18**, and a
base station **20**. In operation, base station **20** can transmit
a signal along backbone connection **18** which is received by
all of the remote units **16**. The signal is transmitted in
turn along all of links **14**, and radiated by all of antennas
12. The signal broadcasted by antennas **12** is received by a
mobile unit (not shown). Communication from base station to
mobile unit is conventionally referred to as a downlink.
Thus the arrangement of **Fig. 1** is suitable for downlink
broadcasting, where the signal is broadcasted from all of
antennas **12** and will reach any mobile unit that is in a
region covered by any of antennas **12**.

Communication from a mobile unit to a base station is
conventionally referred to as an uplink. A signal emitted by
the mobile unit that is received by any of antennas **12** will
reach the base station, so the arrangement of **Fig. 1** is also
suitable for uplink communication from a mobile unit that is
in range (i.e., within a region covered by any of antennas
12).

The key architectural feature of the arrangement of **Fig.
1** is that all signals received at (or transmitted by)

antennas **12** are combined into a single combined signal that is sent via backbone **18** to (or from) base station **20**.

Fig. 2 is a block diagram of a typical multilayer wireless communication infrastructure which serves two (or more) microcell coverage regions **24**. Each region **24** includes several antennas **12** and links **14** between antennas **12** and a hub **26**. In uplink operation to a mobile unit (not shown), each hub **26** provides a hub combined signal **28** which is received by a combiner **30**. Combiner **30** combines all of the hub combined signals to provide a single combined signal **32** which is received by base station **20**. An exemplary application of the arrangement of **Fig. 2** is an airport, where regions **24** correspond to separate terminals of the airport. In addition to uplinking, the arrangement of **Fig. 2** provides downlinking to the mobile unit.

Again, the key architectural feature of the arrangement of **Fig. 2** is that all uplink signals received at antennas **12** are combined into a single combined signal **32** that is sent to base station **20**. In downlink, each signal is sent to all of hubs **26** and then broadcast from all of antennas **12**. We refer to architectures having this feature as distributed antenna systems. Many existing wireless communication systems include such distributed antenna systems.

There is an increasing need for wireless communication systems to provide location information for mobile units, driven in some cases by regulatory pressure (e.g., 911 regulations), and in other cases by a desire to provide location based services to mobile units. Accordingly, various methods for determining mobile unit location are known. These methods include: received signal strength (RSS), cell of origin (COO), time of arrival (TOA), time difference of arrival (TDOA), enhanced observed time difference (E-OTD), angle of arrival (AOA), and enhanced forward link triangulation (EFLT).

All of these methods may be implemented in a system
represented by the block diagram shown in **Fig. 3**. In **Fig. 3**,
n antennas A_1, A_2, ..., A_n (shown as **34**, **36**, ..., **38**
respectively) are in communication with a location processor
46. Location processor **46** separately receives signals S1,
S2, ..., Sn (shown as **40**, **42**, ..., **44** respectively) from
antennas **34**, **36**, ..., **38**, with no combination. Within
location processor **46**, a location algorithm (e.g., one of the
methods listed above) is applied to the separately received
signals to determine location.

However, these location determination methods are not
directly applicable to distributed antenna systems. The
reason for this inapplicability is that, in a distributed
antenna system, the identity of the receiving antenna for
each uplink signal is lost in the process of aggregating all
of the uplink signals into a single combined signal received
by base station **20**. Because the location determination
methods require knowledge of which antenna is associated with
each uplink signal, they do not function in a distributed
antenna system.

Accordingly, it would be an advance in the art to
provide location information in a wireless communication
system having a distributed antenna system.

SUMMARY

In one aspect, the present invention provides a method
for determining the location of a mobile unit where each
uplink signal received at an antenna is tagged with a
corresponding unique antenna tag. All of the tagged uplink
signals are combined into a single combined signal, which may
be communicated to a base station. One or more signal parts
are selected from the combined signal, and these selected
parts are decoded to determine their corresponding antenna

tags. A location algorithm is applied to the decoded signal
parts to determine a location of the mobile unit.

BRIEF DESCRIPTION OF THE DRAWINGS

     Fig. 1 shows a typical single-layer wireless
communication system having a distributed antenna system.

     Fig. 2 shows a typical multi-layer wireless
communication system having a distributed antenna system.

     Fig. 3 is a block diagram of the architecture used with
prior art location determination methods.

     Fig. 4 is a block diagram of a location determination
system in accordance with an embodiment of the invention.

     Fig. 5 is a block diagram of a single-layer location
determination system in accordance with another embodiment of
the invention.

     Fig. 6 is a block diagram of a two-layer location
determination system in accordance with yet another
embodiment of the invention.

DETAILED DESCRIPTION

     Fig. 4 is a block diagram of a location determination
method in accordance with an embodiment of the invention. A
plurality of n antennas A_1, A_2, ..., A_n (shown as **34, 36,
..., 38** respectively) provide a plurality of n corresponding
uplink signals **40, 42, ..., 44**, respectively. The plurality
of uplink signals is received by a combining and encoding
block **50**. Within block **50**, a plurality of encoding circuit
blocks **51, 52, ..., 53** respectively impose unique tags T1,
T2, ..., Tn on uplink signals **40, 42, ..., 44** respectively to
provide encoded signals **54, 55, ..., 56** respectively. No two
of antenna tags T1, T2, ..., Tn are the same. Encoded
signals **54, 55, ..., 56** are then combined in block **50** into a
single combined signal **59**. The encoding of the n uplink

signals with the n unique antenna tags T1, T2, ..., Tn can be implemented in various ways, including but not limited to encoding each uplink signal with: a unique time delay; a unique frequency shift; or a unique modulation of amplitude, frequency and/or subcarrier. Digital tagging by adding a digital header or digital code to the signals is another applicable encoding method.

Combined signal **59** is received by a processor **62**, which selects one or more signal parts, shown as **64, 66, ..., 68** on **Fig. 4**, of combined signal **59** and decodes the selected signal parts to determine which of the antenna tags corresponds to the selected signal parts. The selection of the signal parts may be directly based on the antenna tags (e.g., if processor **62** is a time delay demultiplexor and the antenna tags are time delays). Alternatively, this selection may be based on any characteristic(s) of the signal that permit selection, including but not limited to: received power, bit error rate, Quality, first time of arrival or any combination thereof.

Signal parts **64, 66, ..., 68** correspond to uplink signals **40, 42, ..., 44** received at antennas **34, 36, ..., 38**. Signal parts **64, 66, ..., 68** are received by a location processor **46**, which determines the location of the mobile unit from its separated inputs **64, 66, ..., 68** and from known locations of antennas **34, 36, ..., 38**. Location processor **46** need not receive inputs corresponding to all of antennas **34, 36, ..., 38**. Instead, as indicated above, processor **62** selects one or more signal parts to pass on to location processor **46**, along with decoded antenna tag information for the selected signal parts. Suitable location algorithms for location processor **46** include, for example: received signal strength (RSS), cell of origin (COO), time of arrival (TOA), time difference of arrival (TDOA), and enhanced observed time difference (E-OTD).

The system illustrated in the block diagram of **Fig. 4** may be implemented in hardware in many different ways. For

example, **Fig. 4** shows several point to point links (e.g., transmission from antenna **34** to combining and encoding block **50**). Such point to point links can include, for example, electrical wiring, optical fiber, an RF free space link and/or an optical free space link. Similarly, location processor **46** can be any combination of hardware and/or software suitable for determining mobile unit location based on known locations of antennas **34, 36, ..., 38** and separated inputs **64, 66, ..., 68** corresponding to antennas **34, 36, ..., 38** respectively.

The embodiment of **Fig. 4** provides various advantages. For example, the region within which the plurality of antennas **34, 36, ..., 38** are disposed can be either a two-dimension area or a three dimensional volume (e.g., within a building). Since prior art location determination methods tend to be directed to location within an area, providing location within a volume is an advance in the art. It is also an advance in the art to provide reliable location determination within a building, since prior art location determination methods tend to fail inside buildings, due in part to severe multipath effects and signal attenuation.

In some cases, it is advantageous for location processor **46** to include an antenna location database from which antenna location information can be retrieved. Such a database also provides a useful tool for managing and updating antenna location information, especially for a large scale system having a large number of antennas.

Location processor **46** can advantageously be connected to an external network to provide mobile unit location information to the external network. The external network (or any service provider on the external network) can then provide location based services to the mobile unit based on location information provided by location processor **46** to the network.

The accuracy of the location information provided by the embodiment of **Fig. 4** depends in part on the number and spacing of antennas **34, 36, ..., 38**. Increased location accuracy can be obtained by reducing the spacing between these antennas.

Fig. 5 is a block diagram illustrating one embodiment of the invention using time delay tags. In **Fig. 5**, predetermined and unique time delays $\tau 1$, $\tau 2$, ..., τn are imposed by encoding circuit blocks **51', 52', ..., 53'** respectively on uplink signals **40, 42, ..., 44** respectively to provide delayed signals **54', 55', ..., 56'** respectively. Delayed signals **54', 55', ..., 56'** are combined to provide combined signal **59** to a processor **62'**. In this embodiment, processor **62'** is a time division demultiplexor to separate combined signal **59** into signal parts **64, 66, ..., 68** according to predetermined delays $\tau 1$, $\tau 2$, ..., τn respectively. Delays $\tau 1$, $\tau 2$, ..., τn corresponding to antennas **34, 36, ..., 38** in **Fig. 5** are defined as the total delays between the corresponding antennas and processor **62'**. Such total delays include time of flight along electrical cable and/or optical fiber, as well as any delays provided by one or more lumped delay elements. Lumped delay elements are convenient for setting the total delay of a path to a desired value. In some cases, time of flight delay can be adjusted to set the total delay appropriately (e.g., by choosing optical fiber lengths and/or electrical cable lengths appropriately).

Lumped elements for adjusting total delays of delayed signals **54', 55', ..., 56'** may be, for example, commercially available surface acoustic wave (SAW) filters. In some cases, SAW filters can be used having a bandwidth much larger than the uplink or downlink bandwidth to the mobile unit, which reduces the effect of the SAW filter on the communication link to the mobile unit. Also in some cases, uplink signals **40, 42, ..., 44** may be down-converted from

7

radio frequency (RF) to an intermediate frequency (IF) before adjusting the delays to $\tau 1$, $\tau 2$, ..., τn respectively with SAW filters, since SAW filters at IF tend to be more readily available. Alternatively, elements for adjusting delays of delayed signals **54'**, **55'**, ..., **56'** can be digital delay elements, where the corresponding uplink signal is digitized, digitally delayed, and then converted to an analog signal with a D/A converter. Other delay elements can also be used to practice the invention, such as electrical delay lines, optical fibers and digital delay elements, and of course there is no requirements that the same technology be used for all delay elements in the system. For example, encoding circuit block **51'** could be a SAW filter, and encoding circuit block **52'** could be a digital delay element.

Processor **62'** on **Fig. 5** provides time division demultiplexing of combined signal **59** to provide signal parts **64**, **66**, ..., **68** corresponding to antennas **34**, **36**, ..., **38** respectively. One method for performing this demultiplexing is to sample combined signal **59** at a suitable sampling rate and then time delay demultiplex the sampled signal using standard digital signal processing methods.

To illustrate an aspect of this embodiment, suppose, for example, the mobile unit emits a pulse of radiation which is received by only one of antennas **34**, **36**, ..., **38**. A delay corresponding to the antenna that received the pulse is imposed on the corresponding uplink signal by block **50**. In this example, combined signal **59** is an appropriately delayed pulse. Processor **62'** detects a pulse, and may determine the time delay of that pulse using some information about when the pulse was emitted by the mobile unit.

Such timing information can be provided in various ways. For example, in a system where the mobile unit and remote units are all synchronized to a master clock, the system knows when the pulse was emitted by the mobile unit. Therefore the delay tag applied to the selected signal can be

determined from the time difference between the known
transmission time and the time of arrival of the selected
signal. An alternative method is switch the delay tags on
and off, so that delayed signals are received by processor
62' at some times and non-delayed signals are received by
processor **62'** at other times. In this arrangement, processor
62' can determine the time delay tag from the difference in
time of arrival of the delayed and non-delayed versions of
the signals. Yet another alternative is for the remote units
to provide both delayed and non-delayed signals for inclusion
in the combined signal. In this case as well, processor **62'**
can determine the time delay tag from the difference in time
of arrival of the delayed and non-delayed versions of the
signals.

   Fig. 6 is a block diagram of a second embodiment making
use of time delays as tags for the uplink signals. In this
second version, encoding and combining are done in two
stages, as would be suitable for a two level distributed
antenna system as shown in **Fig. 2.** The configuration of **Fig.
6** has two subsets of antennas, subset A including antennas
A_1, A_2, ..., A_n (labeled **34**, **36**, ..., **38** respectively),
and subset B, including antennas B_1, B_2, ..., B_m (labeled
70, **72**, ..., **74** respectively. Combining and encoding block
50 in **Fig. 6** has two levels of combining and encoding.

   Signals from subset A are received by combining and
encoding sub-block **48.** Delays $\tau1$, $\tau2$, ..., τn, are imposed by
encoding circuit blocks **51''**, **52''**, ..., **53''** respectively,
on uplink signals **40**, **42**, ..., **44** respectively to provide
delayed signals **54'**, **55'**, ..., **56'** that are combined to
provide an intermediate combined signal **94.** The delays
provided by encoding circuit blocks **51''**, **52''**, ..., **53''** in
Fig. 6 are defined to be total delays between antennas **34**,
36, ..., **38** respectively and intermediate combined signal **94.**

   Signals from subset B are received by combining and
encoding sub-block **48'.** Delays $\tau1$, $\tau2$, ..., τm, are imposed

9

by encoding circuit blocks **82, 84, ..., 86** respectively, on uplink signals **76, 78, ..., 80** respectively to provide delayed signals **88, 90, ..., 92** that are combined to provide an intermediate combined signal **96**. The delays provided by encoding circuit blocks **82, 84, ..., 86** in **Fig. 6** are defined to be total delays between antennas **70, 72, ..., 74** respectively and intermediate combined signal **96**.

Intermediate signals **94** and **96** are received and combined by an intermediate combining block **49**, which provides combined signal **59**. In some cases, block **49** also imposes time delays on the intermediate combined signals. For example, in **Fig. 6** time delays TA and TB are imposed on intermediate combined signals **94** and **96**, corresponding to subsets A and B respectively. Delays TA and TB are defined to be the total delays between intermediate combined signals **94** and **96** respectively, and combined signal **59**.

Combined signal **59** is received by processor **62'**, and time delay demultiplexed. In the example of **Fig. 6**, the sums TA+τ1, TA+τ2, ..., TA+τn, TB+τ1, TB+τ2, ..., TB+τm are distinct to permit an unambiguous separation of combined signal **59** into signal parts (shown as **64, 66, ..., 68** and **102, 104, ..., 106** in **Fig. 6**) corresponding to each antenna. There are many ways to provide unique total delays. One method is to make the difference between TA and TB larger than the difference between τ1 and τn, so TA and TB effectively act as the coarse delay adjustment and τ1 through τn (or τm) effectively act as the fine delay adjustment. In this case, the time delays imposed in sub-block **48** can be the same as those imposed in sub-block **48'** (as in the example of **Fig. 6**).

In the example of **Fig. 6**, the antenna tag corresponding to a particular antenna, called antenna X, includes a subset time delay (i.e., TA or TB) to identify the subset antenna X belongs to, and a member time delay (i.e., τ1, τ2, ...) to identify which antenna within this subset is antenna X. More

generally, in an embodiment of the invention having two
levels of combining and encoding, an antenna tag can include
a member tag and a subset tag. Similarly, in an embodiment
having N levels of combining and encoding, an antenna tag can
include N subtags corresponding to the N levels of encoding
and combining.

The above description of embodiments of the invention is
illustrative, rather than restrictive. Many alternatives
fall within the scope of the present invention. For example,
in the embodiments of **Figs. 5** and **6**, processor **62'** is a time
delay demultiplexor, but such demultiplexing is not required
to practice the invention. Instead, as indicated in
connection with **Fig. 4**, processor **62** may select one or more
signal parts, and then decode these selected signal parts to
determine the corresponding antenna tags. Clearly, a full
demultiplexing of the combined signal is not required to
perform these functions.

What is claimed is:

1. A method for determining the location of a mobile unit
within a region, the method comprising:

a) receiving at a plurality of antennas having known
locations within said region a corresponding plurality of
uplink signals originating from the mobile unit;

b) encoding each of said uplink signals with an antenna
tag corresponding to each of said plurality of antennas;

c) combining the encoded uplink signals into a single
combined signal;

d) selecting one or more signal parts of said combined
signal;

e) decoding said signal parts to determine which of said
antenna tags corresponds to each of said signal parts; and

f) determining said location in part from said known
locations of said plurality of antennas, said signal parts,
and said decoding.

2. The method of claim 1, wherein said region is an indoor
region.

3. The method of claim 1, wherein said region is a two
dimensional area.

4. The method of claim 1, wherein said region is a three
dimensional volume.

5. The method of claim 1, wherein said determining comprises
retrieving said known locations from a database of known
antenna locations.

6. The method of claim 1, further comprising providing said
determined location to a network.

7. The method of claim 6, further comprising providing a location based service to said mobile unit by said network.

8. The method of claim 1, wherein said combining comprises:

   i) providing a partitioning of said antennas into subsets of antennas, wherein each of said antennas is a member of one of said subsets;

   ii) combining said encoded uplink signals to generate a set of intermediate combined signals, wherein each intermediate combined signal is obtained by combining encoded uplink signals received from one of the subsets of antennas; and

   iii) combining said intermediate combined signals to provide said combined signal.

9. The method of claim 8, wherein said encoding each of said uplink signals with an antenna tag comprises: providing a member tag for each antenna in each of said subsets, and providing a subset tag for each of said subsets, wherein no two antennas of said plurality have the same combination of member tag and subset tag.

10. The method of claim 9, wherein said providing a member tag comprises providing a member time delay, and wherein said providing a subset tag comprises providing a subset time delay, wherein no two antennas of said plurality have the same sum of member time delay and subset time delay.

11. The method of claim 9, wherein said providing a member tag comprises providing a member frequency shift, and wherein said providing a subset tag comprises providing a subset frequency shift, wherein no two antennas of said plurality have the same sum of member frequency shift and subset frequency shift.

12. The method of claim 1, wherein said determining a
location uses a location algorithm selected from the group
consisting of received signal strength, cell of origin, time
of arrival, time difference of arrival, and enhanced observed
time difference.

13. The method of claim 1, wherein said antenna tag is
selected from the group consisting of: a unique time delay, a
unique frequency shift, a unique modulation, a unique digital
header, and a unique digital code.

14. The method of claim 1, wherein said encoding each of said
uplink signals with an antenna tag comprises passing each of
said uplink signals through a surface acoustic wave (SAW)
delay element.

15. The method of claim 14, further comprising frequency
down-converting one of said uplink signals to an intermediate
frequency before said one signal passes through said SAW
delay element.

16. The method of claim 1, wherein said encoding each of said
uplink signals with an antenna tag comprises passing each of
said uplink signals through a digital delay element.

17. A wireless communication system capable of providing
location information for a mobile unit within a region, the
system comprising:
        a) a plurality of antennas having known locations within
said region for receiving a plurality of uplink signals
transmitted from the mobile unit;
        b) a plurality of encoding circuit blocks coupled to the
plurality of antennas, wherein the encoding circuit blocks
impose antenna tags on the uplink signals;

c) a combining circuit block connected to the encoding circuit blocks to receive said encoded uplink signals and output a single combined signal;

d) a processor in communication with the combining circuit block for receiving said combined signal, selecting one or more signal parts of said combined signal, and decoding said signal parts to determine which of said antenna tags corresponds to each of said signal parts; and

e) a location processor connected to the processor to receive said signal parts, wherein the location processor determines said location information in part from said known antenna locations, said signal parts, and said decoding using a location algorithm.

18. The system of claim 17, wherein said region is an indoor region.

19. The system of claim 17, wherein said region is a two dimensional area.

20. The system of claim 17, wherein said region is a three dimensional volume.

21. The system of claim 17, wherein said location processor further comprises a database of known antenna locations.

22. The system of claim 17, further comprising a network connected to said location processor, wherein the network receives said determined location from said location processor.

23. The system of claim 22, wherein said network provides a location based service to said mobile unit.

24. The system of claim 17, wherein said combining circuit block comprises:

    i) a plurality of combining circuit sub-blocks for combining subsets of said encoded uplink signals into intermediate combined signals; and

    ii) an intermediate combining block receiving the intermediate combined signals and producing said combined signal.

25. The system of claim 24, further comprising intermediate encoding blocks imposing subset tags upon said intermediate combined signals.

26. The system of claim 25, wherein each of said antenna tags comprises a member time delay, and wherein each of said subset tags comprises a subset time delay, wherein the sum of said member time delay and said subset time delay is unique.

27. The system of claim 25, wherein each of said antenna tags comprises a member frequency shift, and wherein each of said subset tags comprises a subset frequency shift, wherein the sum of said member frequency shift and said subset frequency shift is unique.

28. The system of claim 17, wherein said location algorithm is selected from the group consisting of received signal strength, cell of origin, time of arrival, time difference of arrival, and enhanced observed time difference.

29. The system of claim 17, wherein said antenna tag is selected from the group consisting of: a unique antenna time delay, a unique antenna frequency shift, a unique antenna modulation, a unique digital header, and a unique digital code.

30. The system of claim 17, wherein one of said encoding
circuit blocks comprises a surface acoustic wave (SAW) delay
element.

31. The system of claim 30, further comprising a frequency
down-converter circuit connected to one of said antennas to
down-convert one of the uplink signals to an intermediate
frequency and provide the down-converted uplink signal to
said SAW delay element.

32. The system of claim 17, wherein one of said encoding
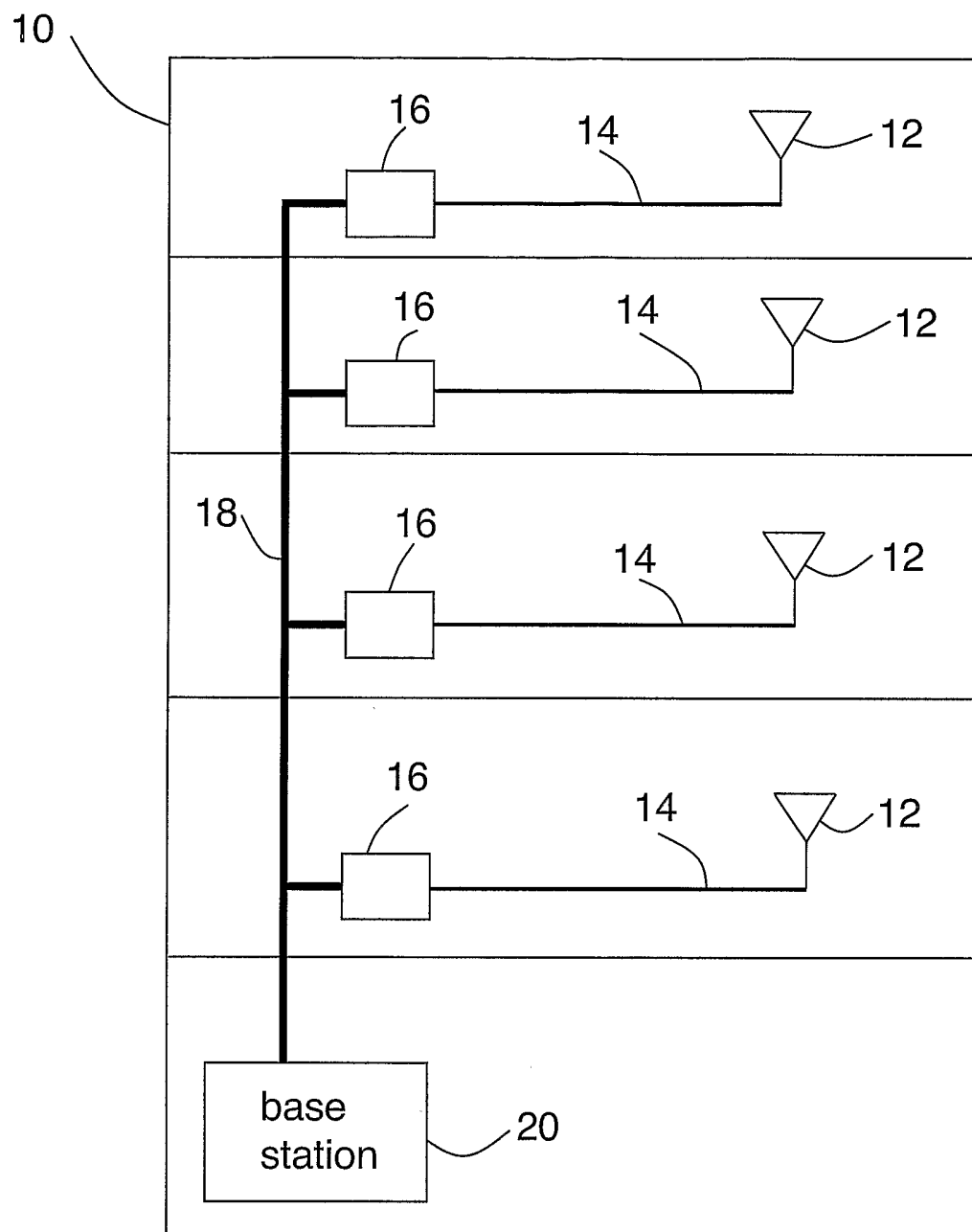circuit blocks comprises a digital delay element.

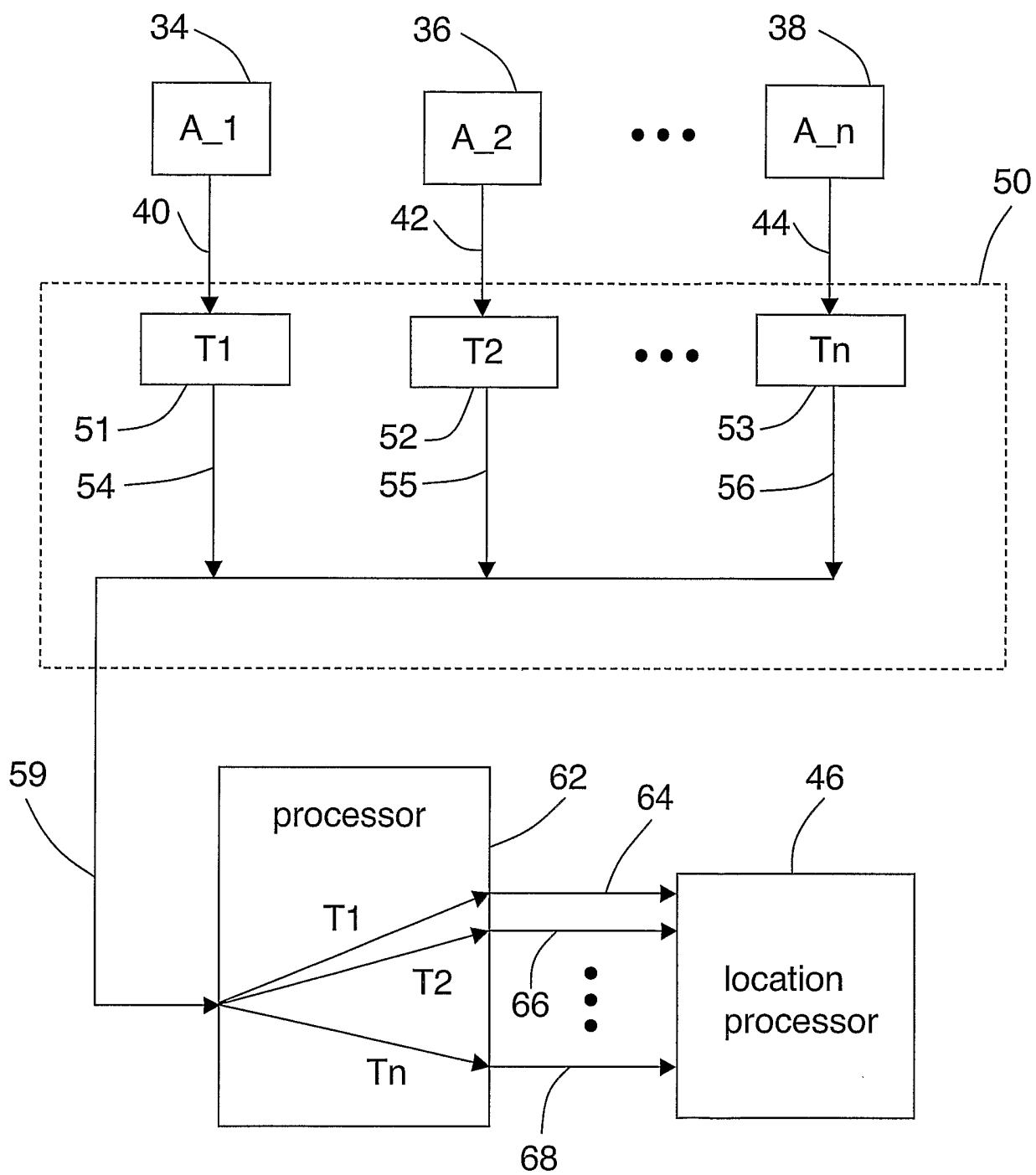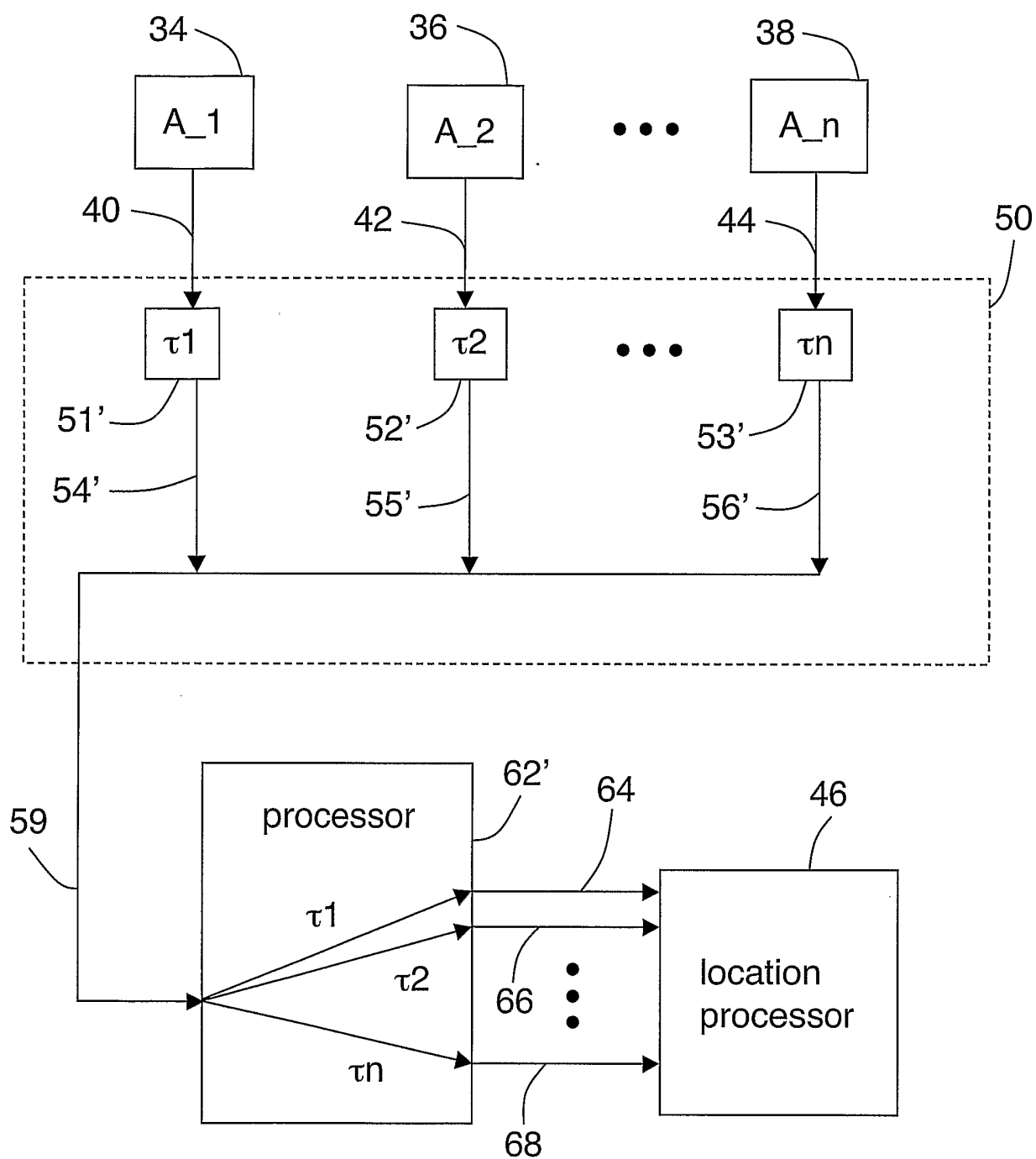Fig. 1 (PRIOR ART)
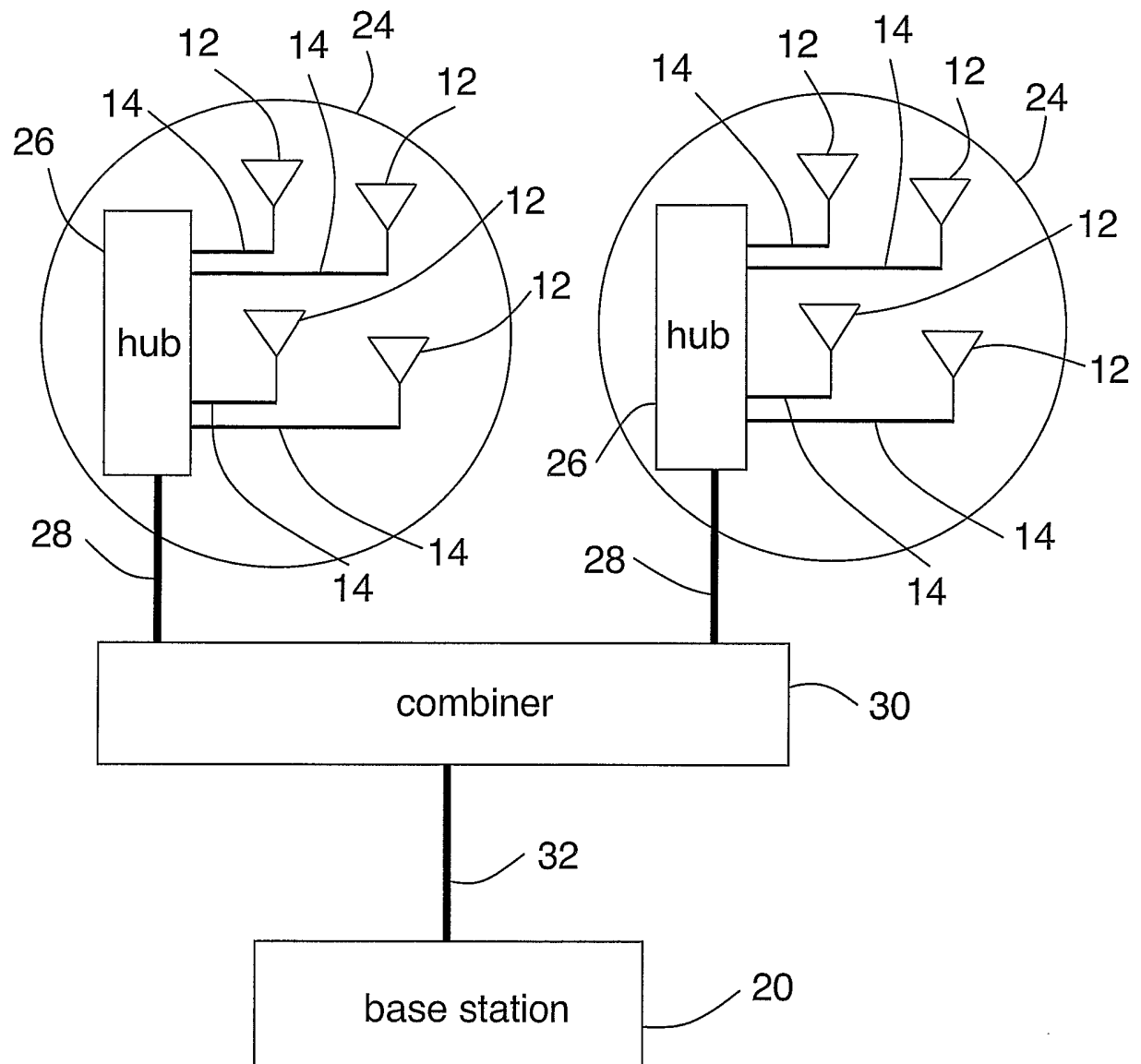
Fig. 2 (PRIOR ART)
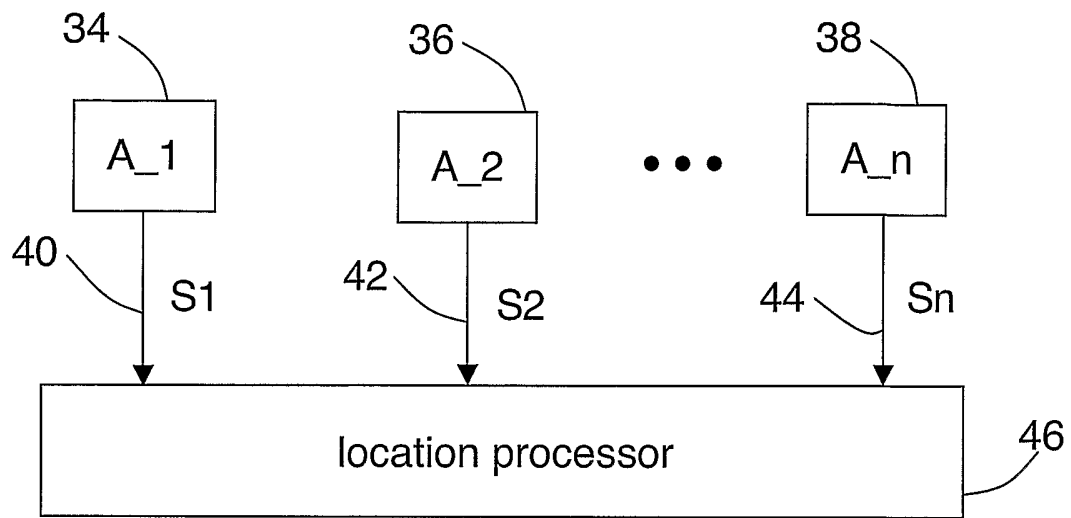
Fig. 3 (PRIOR ART)

Fig. 4

Fig. 5

Fig. 6