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Appendix A: Details of the 1-4-1 Six-Unit Configuration Analysis

Analysis of 1-4-1 Six-Unit Configuration, No Middle Units Within Range of Each Other

In the six-unit configuration shown in row one of Table 6.3, none of the middle units is within range of one another. Unit six will not receive an alarm message if all of the middle units transmit such that their messages collide because they cannot hear one another's transmissions. The probability of this occurring is given by equation (A.1).

Pr{Unit six does not receive message}
= Pr {None of the messages transmitted by units two, three, four, and five are successfully received by unit six}
= (0.6043)(0.6043)(0.6043)
= 0.2207 (A.1)

Analysis of 1-4-1 Six-Unit Configuration, One Pair of Middle Units Within Range of Each Other

In row two of Table 6.3, one pair of the middle units are within range with each other. In the following analysis, we assume that units three and four are the two middle units that are within range of one another. Unit six will not receive an alarm message if either of the following two conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units three and four are synchronized. Units two and five cannot hear transmissions generated by units three and four. None of the messages generated by any of the middle units is successfully received by unit six.

The probability that unit six does not receive an alarm message in this configuration is shown in equation (A.2).

Pr{Unit six does not receive message}
= Pr {Holdoff timers in units two, three, four, and five are synchronized} +
Pr {Holdoff timers in units three and four are synchronized} ×
Pr {Transmissions generated by units two and five are not successfully received by unit six}
= (0.0625)(0.0625)(0.0625) + (0.0625)(0.6043)(0.6043)
= 0.0231 (A.2)

Analysis of 1-4-1 Six-Unit Configuration, Two Non-Adjacent Pairs of Middle Units Within Range of Each Other

In row three of Table 6.3, two non-adjacent pairs of middle units are within range of one another. In this example, we assume that units two and three can hear one another, and

units four and five can hear one another. Unit six will not receive an alarm message if either of the following two conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two and three are synchronized, and the holdoff timers in units four and five are synchronized. Messages generated by units four and five are not successfully received by unit six since units four and five cannot hear messages generated by units two and three.

The probability that unit six does not receive an alarm message in this configuration is given in equation (A.3).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= Pr\{\text{Holdoff timers in units two, three, four, and five are synchronized}\} + \\
&\quad Pr\{\text{Holdoff timers in units two and three are synchronized}\} \times \\
&\quad Pr\{\text{Holdoff timers in units four and five are synchronized}\} \times \\
&\quad Pr\{\text{Unit six does not successfully receive messages generated by units two, three, four, and five}\} \\
&= (0.0625)(0.0625)(0.0625) + (0.0625)(0.0625)(0.6043) \\
&= 0.0026
\end{aligned}
\tag{A.3}
$$

Analysis of 1-4-1 Six-Unit Configuration, Two Adjacent Pairs of Middle Units Within Range of Each Other

In row four of Table 6.3, two adjacent pairs of middle units are within range of one another. For this example, we assume that units two and three can hear one another, and units three and four can hear one another. Unit six will not receive an alarm message if any of the following three conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, three, and four are synchronized. Unit five cannot hear the transmissions of units two, three, and four, and none of its messages are successfully received by unit six.
(3) Units two and four transmit before unit three. Since units two and four cannot hear one another, none of their messages are successfully received by unit six. Unit three cannot hear the messages generated by units two and four. Unit five cannot hear the messages generated by units two, three, and four. As a result, none of the messages are successfully received by unit six.

The probability that unit six does not receive an alarm message in this configuration is shwon in equation (A.4).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= Pr\{\text{Holdoff timers in units two, three, four, and five are synchronized}\} +
\end{aligned}
$$

Pr {Holdoff timers in units two, three, and four are synchronized} ×
Pr {None of unit five's transmissions are successfully received by unit six} +
Pr {Units two and four transmit before unit three}×
Pr {None of the messages generated by units two and four are received by unit six} ×
Pr {None of the messages generated by units three and five are received by unit six}

$$= (0.0625)(0.0625)(0.0625) + (0.0625)(0.0625)(0.6043) + (0.6667)(0.6043)(0.6043)(0.6043)$$
$$= 0.1497 \quad \text{(A.4)}$$

Analysis of 1-4-1 Six-Unit Configuration, Three Adjacent Pairs of Middle Units Within Range of Each Other

In row five of Table 6.3, three adjacent pairs of middle units are within range of one another. For this example, we assume that units two and three are within range, units three and four are within range, and units four and five are within range. Unit six will not receive an alarm message if any of the following three conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, four, and five are synchronized. Units two, four, and five begin transmitting before unit three. Unit three cannot hear the transmissions. None of unit three's messages are successfully received by unit six.
(3) The holdoff timers in units two, three, and five are synchronized. Units two, three, and five begin transmitting before unit four. Unit four cannot hear the transmissions. None of unit four's messages are successfully received by unit six.

The probability of conditions two and three is identical. In the following analysis, we compute the probability of condition two and double the result. The probability that unit six does not receive an alarm message in this configuration is given by equation (A.5).

Pr{Unit six does not receive message}
= Pr {Holdoff timers in units two, three, four, and five are synchronized} +
2 ×*Pr {Holdoff timers in units two, four, and five are synchronized}* ×
Pr {Units two, four, and five begin transmitting before unit three} ×
Pr {None of unit three's messages are successfully received by unit six}

$$= (0.0625)(0.0625)(0.0625) + 2(0.0625)(0.0625)(0.5)(0.6043)$$
$$= 0.0026 \quad \text{(A.5)}$$

Analysis of 1-4-1 Six-Unit Configuration, Two Adjacent Pairs and Outer Units of Adjacent Pairs Within Range of Each Other

In row six of Table 6.3, two adjacent pairs of middle units are within range of one another. The outer two units of the adjacent pairs can also hear one another. For this example, we assume that units two and three are within range, units three and four are

within range, and units two and four are within range of one another. Unit six will not receive an alarm message if any of the following five conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, three, and four are synchronized. Unit five cannot hear the transmissions. None of unit five's messages are successfully received by unit six.
(3) The holdoff timers in units two and four are synchronized. Units two and four begin transmitting before unit three. Units three and five cannot hear the messages generated by units two and four. None of the messages are successfully received by unit six.
(4) The holdoff timers in units three and four are synchronized. Units three and four begin transmitting before unit two. Units two and five cannot hear the messages generated by units three and four. None of the messages are successfully received by unit six.
(5) The holdoff timers in units two and three are synchronized. Units two and three begin transmitting before unit four. Units four and five cannot hear the messages generated by units two and three. None of the messages are successfully received by unit six.

The probability of conditions three, four, and five is identical. In the following analysis, we compute the probability of condition three and triple the result. The probability that unit six does not receive an alarm message in this configuration is given in equation (A.6).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= Pr\{\text{Holdoff timers in units two, three, four, and five are synchronized}\} + \\
&\quad Pr\{\text{Holdoff timers in units two, three, and four are synchronized}\} \times \\
&\quad Pr\{\text{None of unit five's messages are successfully received by unit six}\} + \\
&\quad 3 \times Pr\{\text{Holdoff timers in units two and four are synchronized}\} \times \\
&\quad Pr\{\text{Units two and four begin transmitting before unit three}\} \times \\
&\quad Pr\{\text{None of the messages generated by units three and five are successfully received by unit six}\} \\
&= (0.0625)(0.0625)(0.0625) + (0.0625)(0.0625)(6043) + \\
&\quad 3(0.0622)(0.5)(0.6043)(0.6043) \\
&= 0.0368
\end{aligned}
\qquad \text{(A.6)}
$$

Analysis of 1-4-1 Six-Unit Configuration, Three Adjacent Pairs and Additional Pair Separated by One Middle Unit Within Range of Each Other

In row seven of Table 6.3, three adjacent pairs of middle units are within range of one another. An additional pair of middle units that are separated by one middle unit are within range of one another. For this example, we assume that units two and four are the additional pair of middle units that are within range of each other. Unit six will not receive an alarm message if any of the following seven conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, four, and five are synchronized. Units two, four, and five begin transmitting before unit three. None of unit three's messages are successfully received by unit six.
(3) The holdoff timers in units two, three, and five are synchronized. Units two, three, and five begin transmitting before unit four. None of unit four's messages are successfully received by unit six.
(4) The holdoff timers in units three, four, and five are synchronized. Units three, four, and five begin transmitting before unit two. None of unit two's messages are successfully received by unit six.
(5) The holdoff timers in units two and three are synchronized. Units two and three begin transmitting before units four and five. Unit five transmits next, and none of its messages are successfully received by unit six. Unit four transmits last, and none of its messages are successfully received by unit six.
(6) Units three and five are the first two units to transmit. None of their messages are successfully received because they cannot hear one another. Unit four cannot distinguish the simultaneous transmissions of units three and five. Its messages also are not received. Unit two cannot hear the simultaneous transmissions of units three and four. None of unit two's messages are successfully received by unit six.
(7) Units two and five are the first two units to transmit. None of their messages are successfully received because they cannot hear one another. Unit four cannot distinguish the simultaneous transmissions of units two and five. Its messages also are not received. Unit three cannot hear the simultaneous transmissions of units two and five. None of unit three's messages are successfully received by unit six.

The probability of conditions two through four is identical. In the following analysis, the probability of condition two is evaluated and the result tripled. Likewise, the probability of conditions six and seven is identical. In this case, the probability of condition six is evaluated and doubled in the analysis. The probability that unit six does not receive an alarm message in this configuration is given in equation (A.7).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= Pr\{\text{Holdoff timers in units two, three, four, and five are synchronized}\} + \\
&\quad 3 \times Pr\{\text{Holdoff timers in units two, four, and five are synchronized}\} \times \\
&\quad Pr\{\text{Units two, four, and five begin transmitting before unit three}\} \times \\
&\quad Pr\{\text{None of unit three's messages are successfully received by unit six}\} + \\
&\quad Pr\{\text{Holdoff timers in units two and three are synchronized}\} \times \\
&\quad Pr\{\text{Units two and three begin transmitting before units four and five}\} \times \\
&\quad Pr\{\text{Unit five transmits next, and none of its messages are successfully received by unit six}\} \times \\
&\quad Pr\{\text{Unit four transmits last, and none of its messages are}
\end{aligned}
$$

successfully received by unit six} +
2 ×Pr {Units three and five are the first two units to transmit} ×
Pr{None of the messages generated by units two and five are successfully received because they cannot hear one another's transmissions} ×
Pr{Unit four transmits next, and none of its messages are successfully received} ×
Pr {Unit two transmits because it cannot hear the simultaneous transmissions of units three and four. None of unit two's messages are successfully received by unit six}
= (0.0625)(0.0625)(0.0625) + 3(0.0625)(0.0625)(0.5)(0.6043) + (0.0625)(0.3333)(0.5)(0.6043)(0.6043) + 2(0.0833)(0.6043)(0.6043)(0.6043)
= 0.0444 (A.7)

Analysis of 1-4-1 Six-Unit Configuration, Three Adjacent Pairs and Additional Pair Separated by Two Middle Units Within Range of Each Other

In row eight of Table 6.3, three adjacent pairs of middle units are within range of one another. An additional pair of middle units that are separated by two middle units are within range of one another. Unit six will not receive an alarm message if any of the following seven conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, three, and four are synchronized. Units two, three, and four begin transmitting before unit five. None of unit five's messages are successfully received by unit six.
(3) The holdoff timers in units three, four, and five are synchronized. Units three, four, and five begin transmitting before unit two. None of unit two's messages are successfully received by unit six.
(4) The holdoff timers in units two, four, and five are synchronized. Units two, four, and five begin transmitting before unit three. None of unit three's messages are successfully received by unit six.
(5) The holdoff timers in units two, three, and five are synchronized. Units two, three, and five begin transmitting before unit four. None of unit four's messages are successfully received by unit six.
(6) The holdoff timers in units two and four are synchronized. Units two and four transmit before units three and five. None of the messages generated by units three and five are successfully received by unit six.
(7) The holdoff timers in units three and five are synchronized. Units three and five transmit before units two and four. None of the messages generated by units two and four are successfully received by unit six.

The probability of conditions two through five is identical and is evaluated only once in the following analysis. The result is multiplied by four. The probability of conditions six and seven is also identical. Again, this result is evaluated only once and is doubled. The

probability that unit six does not receive an alarm message in this configuration is shown in equation (A.8).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= Pr\{\text{Holdoff timers in units two, three, four, and five are synchronized}\} + \\
&\quad 4 \times Pr\{\text{Holdoff timers in units two, three, and four are synchronized}\} \times \\
&\quad Pr\{\text{Units two, three, and four begin transmitting before unit five}\} \times \\
&\quad Pr\{\text{None of unit five's messages are successfully received by unit six}\} + \\
&\quad 2 \times Pr\{\text{The holdoff timers in units two and four are synchronized}\} \times \\
&\quad Pr\{\text{Units two and four transmit before units three and five}\} \times \\
&\quad Pr\{\text{None of the messages generated by units three and five are successfully} \\
&\qquad \text{received by unit six}\} \\
&= (0.0625)(0.0625)(0.0625) + 4(0.0625)(0.0625)(0.5)(0.6043) + \\
&\quad 2(0.0625)(0.3333)(0.6043)(0.6043) \\
&= 0.0202
\end{aligned}
\tag{A.8}
$$

Analysis of 1-4-1 Six-Unit Configuration, Three Adjacent Pairs of Middle Units Within Range of Each Other, One Middle Unit Within Range of All Middle Units

In row nine of Table 6.3, three adjacent pairs of middle units are within range of one another. In addition, one of the middle units can hear all of the other middle units. For this example, we assume that unit two is the middle unit which is within range of all of the other middle units. Unit six will not receive an alarm message if any of the following eleven conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, three, and four are synchronized. Units two, three, and four begin transmitting before unit five. None of unit five's messages are successfully received by unit six.
(3) The holdoff timers in units two, three, and five are synchronized. Units two, three, and five begin transmitting before unit four. None of unit four's messages are successfully received by unit six.
(4) The holdoff timers in units two, four, and five are synchronized. Units two, four, and five begin transmitting before unit three. None of unit three's messages are successfully received by unit six.
(5) The holdoff timers in units three, four, and five are synchronized. Units three, four, and five begin transmitting before unit two. None of unit two's messages are successfully received by unit six.
(6) Units three and five transmit before units two and four. None of the messages generated by units three and five are successfully received by unit six, since units three and five cannot hear one another's transmissions. Units two and four both hear the simultaneous transmissions of units three and five, and in turn, think that the channel is idle. As a result, none of the transmissions generated by units two and

four are successfully received by unit six.

(7) The holdoff timers in units two and four are synchronized. Units two and four transmit first. Units three and five think that the channel is idle, and initiate their transmissions. None of the messages generated by units three and five are successfully received by unit six.

(8) The holdoff timers in units two and three are synchronized. Units two and three transmit first. Unit four, thinking the channel is idle, transmits next. None of unit four's messages are successfully received by unit six. Unit five then also thinks the channel is idle and initiates its transmissions. None of the messages generated by unit five are successfully received by unit six.

(9) The holdoff timers in units two and five are synchronized. Units two and five transmit first. Unit four, thinking the channel is idle, transmits next. None of unit four's messages are successfully received by unit six. Unit three then also thinks the channel is idle and initiates its transmissions. None of the messages generated by unit three are successfully received by unit six.

(10) The holdoff timers in units three and four are synchronized. Units three and four transmit first. Unit two, thinking the channel is idle, transmits next. None of unit two's messages are successfully received by unit six. Unit five then also thinks the channel is idle and initiates its transmissions. None of the messages generated by unit five are successfully received by unit six.

(11) The holdoff timers in units four and five are synchronized. Units four and five transmit first. Unit two, thinking the channel is idle, transmits next. None of unit two's messages are successfully received by unit six. Unit three then also thinks the channel is idle and initiates its transmissions. None of the messages generated by unit three are successfully received by unit six.

The probability of conditions two through five is identical and is evaluated only once in the following analysis. The result is multiplied by four. Also, the probability of conditions eight through eleven is identical. Again, this result is evaluated only once and multiplied by four.

The probability that unit six does not receive an alarm message in this configuration is given by equation (A.9).

$$
\begin{aligned}
&Pr\{\text{Unit six does not receive message}\} \\
&= (0.0625)(0.0625)(0.0625) + 4(0.0625)(0.0625)(0.5)(0.6043) + \\
&\quad (0.1667)(0.6043)(0.6043)(0.6043) + 4(0.0625)(0.0833)(0.6043)(0.6043) + \\
&\quad (0.0625)(0.3333)(0.6043)(0.6043) \\
&= 0.0570
\end{aligned}
\tag{A.9}
$$

Analysis of 1-4-1 Six-Unit Configuration, All Middle Units Within Range of Each Other

In row ten of Table 6.3, all of the middle units are within range of one another. Unit six will not receive an alarm message if any of the following eleven conditions occurs:

(1) The holdoff timers in units two, three, four, and five are synchronized.
(2) The holdoff timers in units two, three, and four are synchronized. Units two, three, and four begin transmitting before unit five. None of unit five's messages are successfully received by unit six.
(3) The holdoff timers in units two, three, and five are synchronized. Units two, three, and five begin transmitting before unit four. None of unit four's messages are successfully received by unit six.
(4) The holdoff timers in units two, four, and five are synchronized. Units two, four, and five begin transmitting before unit three. None of unit three's messages are successfully received by unit six.
(5) The holdoff timers in units three, four, and five are synchronized. Units three, four, and five begin transmitting before unit two. None of unit two's messages are successfully received by unit six.
(6) The holdoff timers in units two and three are synchronized. Units two and three transmit before units four and five. Units four and five think that the channel is idle and initiate their transmissions. None of the messages generated by units four and five are successfully received by unit six.
(7) The holdoff timers in units two and four are synchronized. Units two and four transmit before units three and five. Units three and five think that the channel is idle and initiate their transmissions. None of the messages generated by units three and five are successfully received by unit six.
(8) The holdoff timers in units two and five are synchronized. Units two and five transmit before units three and four. Units three and four think that the channel is idle and initiate their transmissions. None of the messages generated by units three and four are successfully received by unit six.
(9) The holdoff timers in units three and four are synchronized. Units three and four transmit before units two and five. Units two and five think that the channel is idle and initiate their transmissions. None of the messages generated by units two and five are successfully received by unit six.
(10) The holdoff timers in units three and five are synchronized. Units three and five transmit before units two and four. Units two and four think that the channel is idle and initiate their transmissions. None of the messages generated by units two and four are successfully received by unit six.
(11) The holdoff timers in units four and five are synchronized. Units four and five transmit before units two and three. Units two and three think

that the channel is idle and initiate their transmissions. None of the messages generated by units two and three are successfully received by unit six.

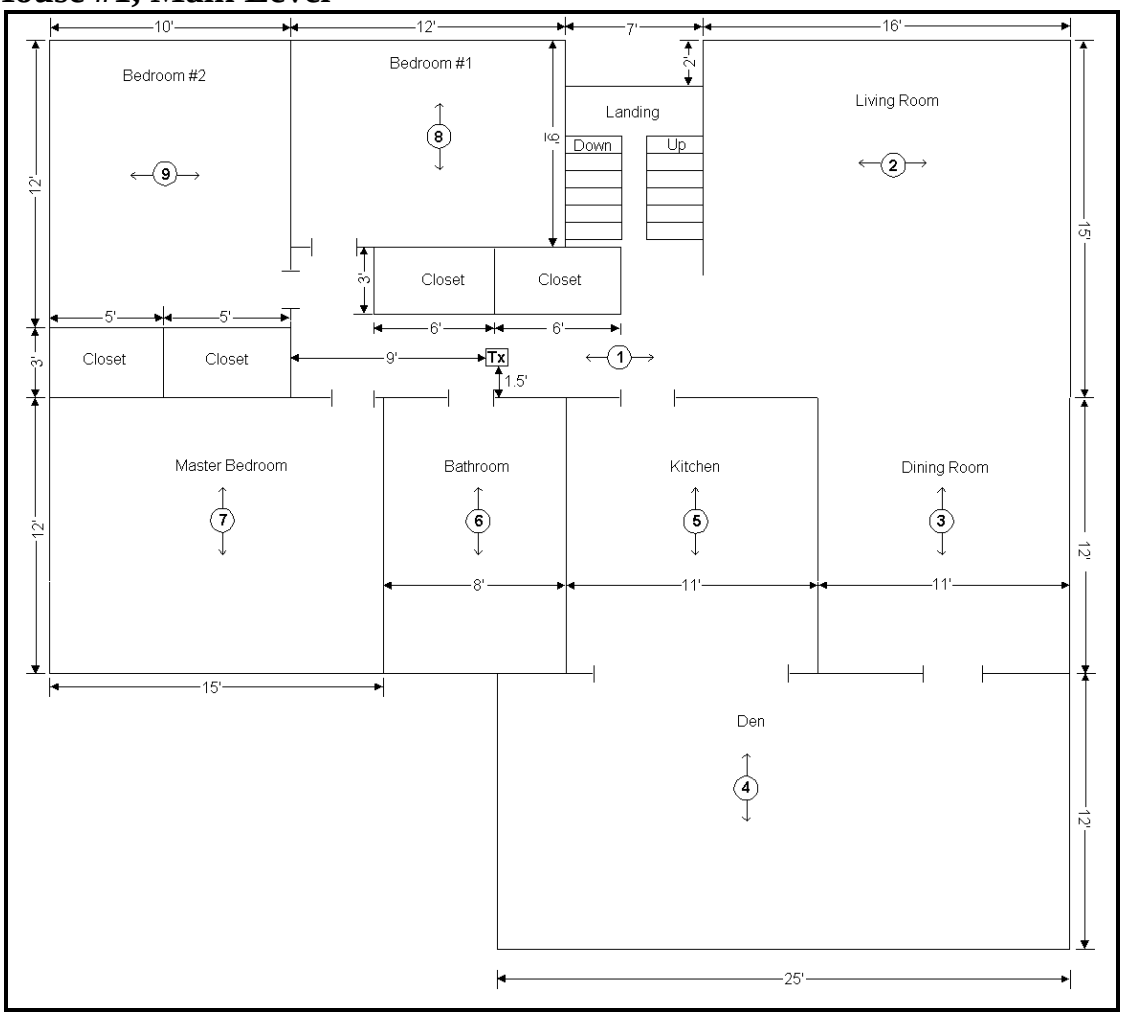
The probability of conditions two through five is identical and is evaluated only once in the following analysis. The result is multiplied by four. Also, the probability of conditions six through eleven is identical. Again, this result is evaluated only once and multiplied by six.

The probability that unit six does not receive an alarm message in this configuration is given in equation (A.10).

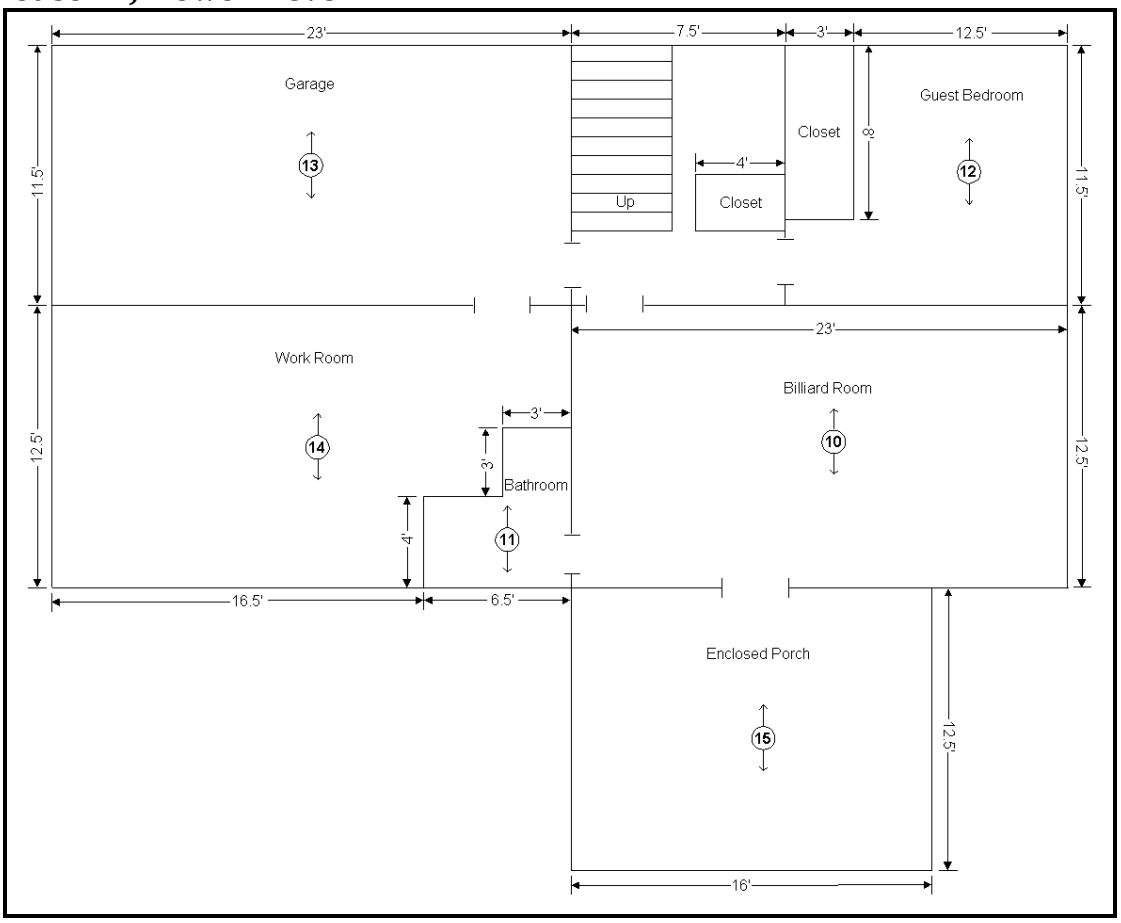
$$\begin{aligned} &Pr\{\text{Unit six does not receive message}\} \\ &= (0.0625)(0.0625)(0.0625) + 4(0.0625)(0.0625)(0.5)(0.6043) + \\ &\quad 6(0.0625)(0.3333)(0.6043)(0.6043) \\ &= 0.0506 \end{aligned} \tag{A.10}$$

Appendix B: Floor Plans of House #1

House #1, Main Level

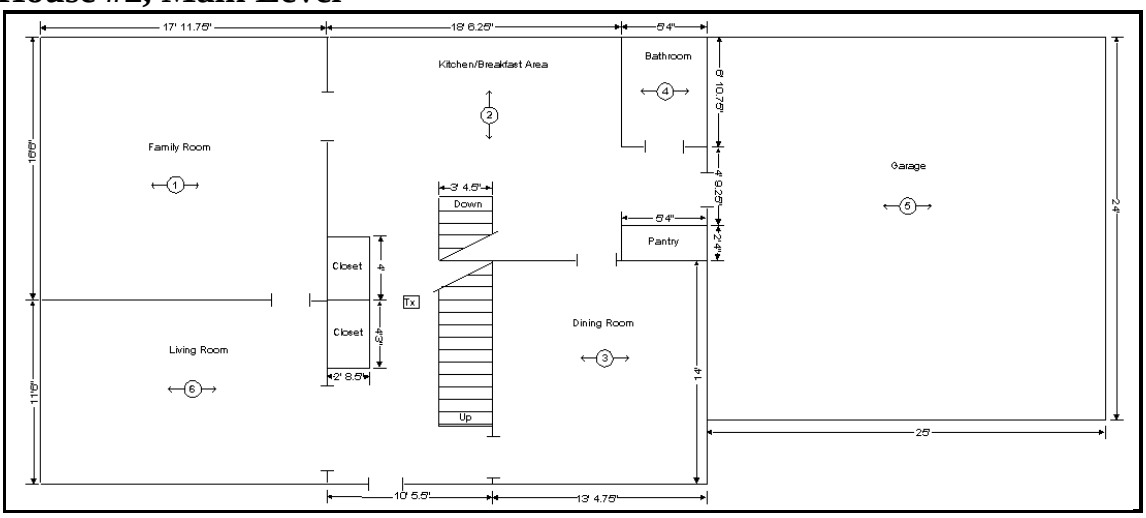


House #1, Lower Level

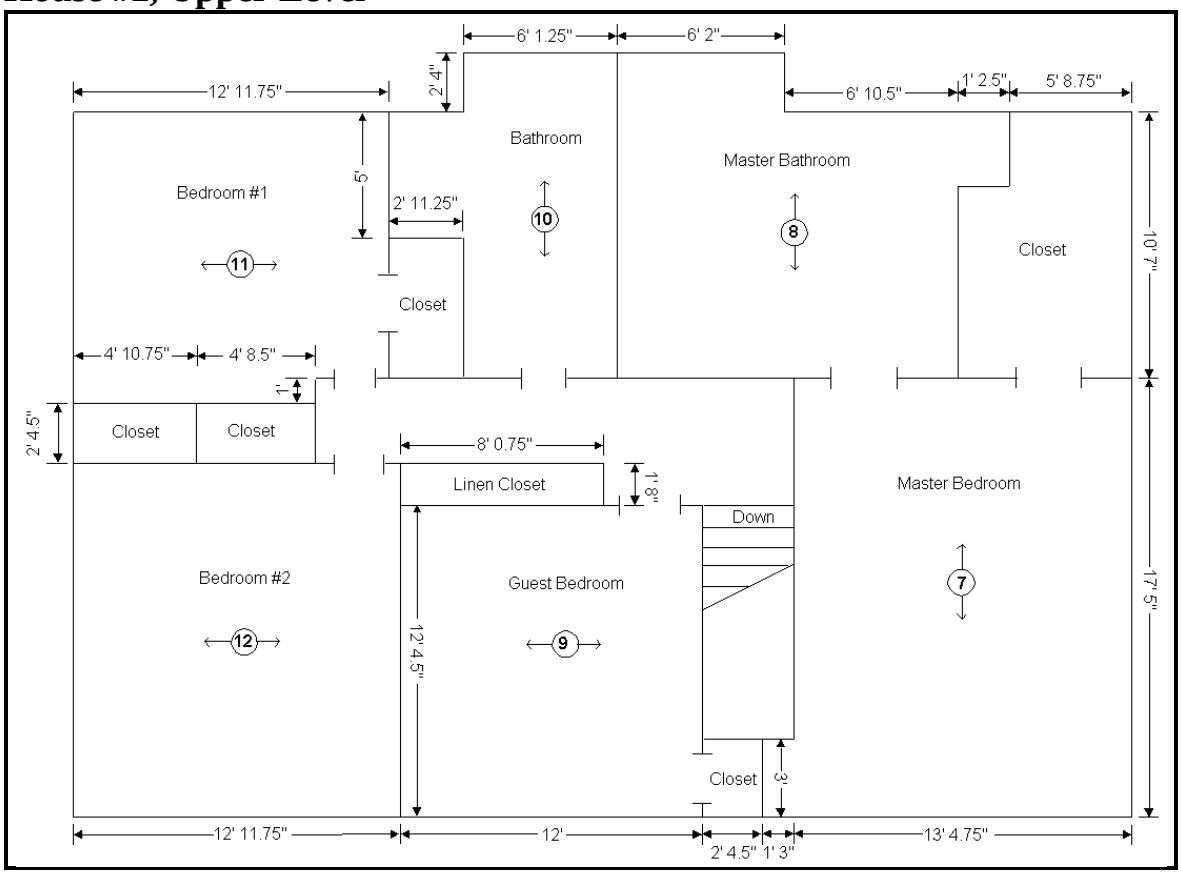


Appendix C: Floor Plans of House #2

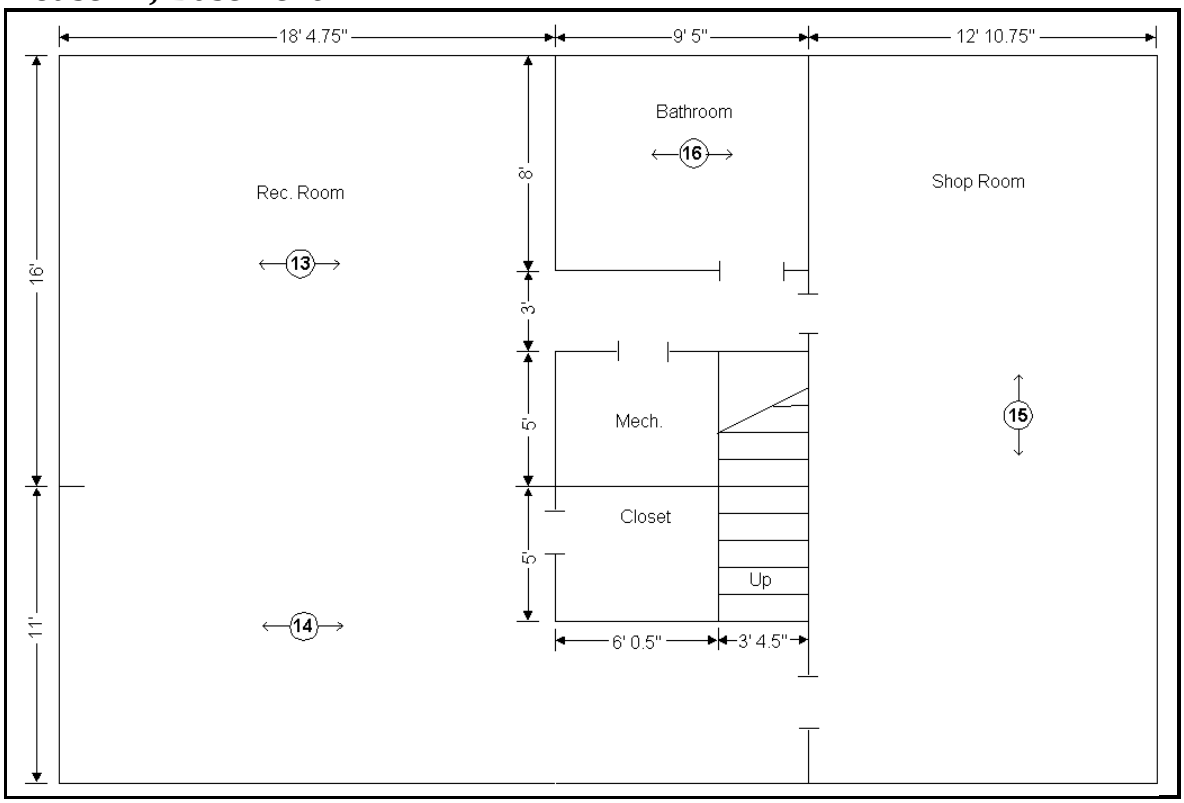
House #2, Main Level



House #2, Upper Level

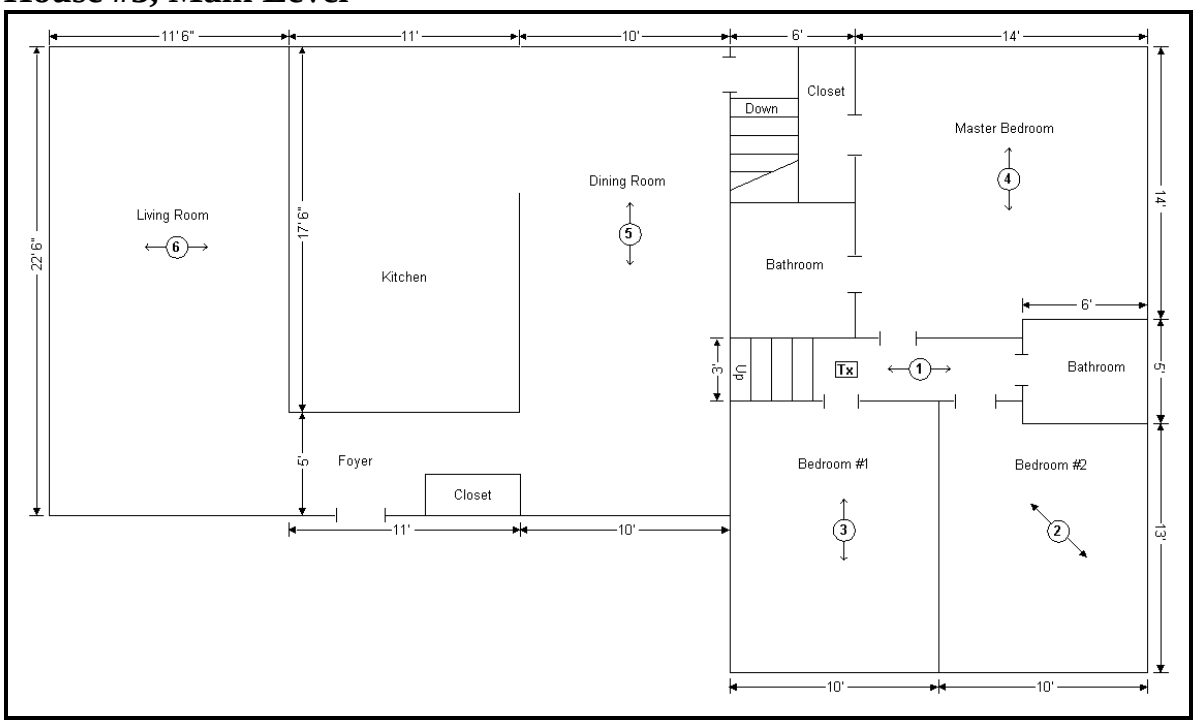


House #2, Basement

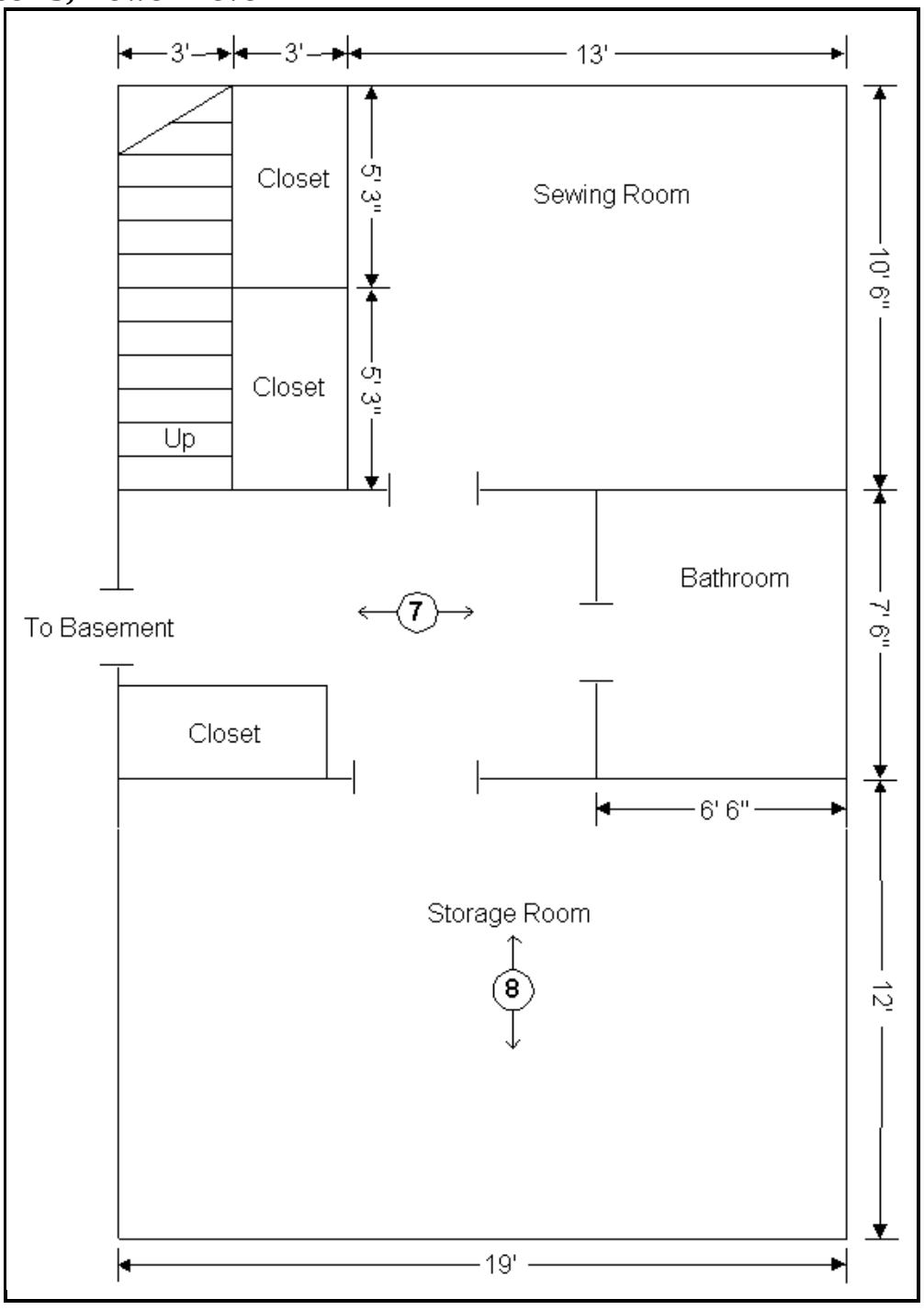


Appendix D: Floor Plans of House #3

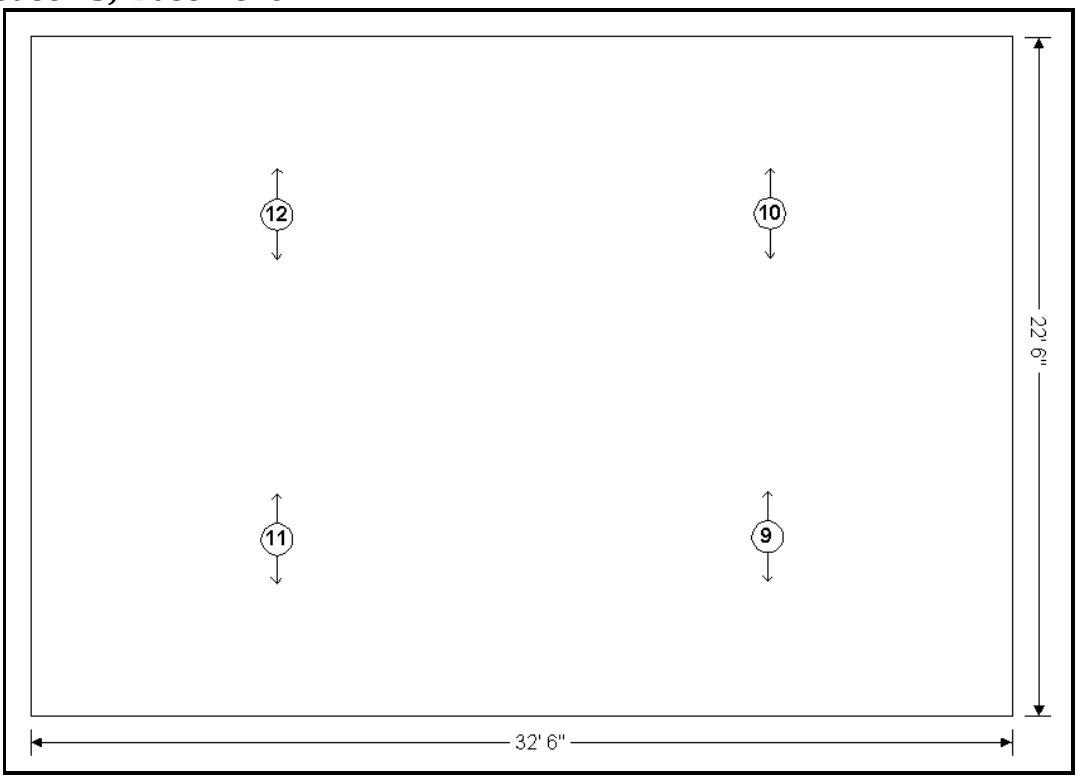
House #3, Main Level



House #3, Lower Level



House #3, Basement



VITA

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