A 4-packets Train Measurement Method

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Abstract. In order to measure more network performance parameters, a 4-packets trains measurement method was put forward, which could measure the network performance of delay variation and network loss, the method did not need time synchronization. Use the parameters of delay variation and loss, the correlation between destination nodes could be calculated, and the correlation could be used to inference network topology.

1. Introduction
In 1999, Ratnasamy first observed the correlation between nodes when measuring network loss, then the correlation was used in multicast network topology inference [1]. Duffield proved the correctness of topology inference based on correlation and used other performance parameters in multicast network topology inference [2].

In order to improve the correctness of network topology inference and reduce the complex of correlation computing, a multicast network topology inference algorithm based on hamming distance was proposed [3], and the hamming distance could be computed based on link idle percentage. While multicast network topology inference based on hamming distance was only suited for lightly loaded networks and sometimes inferred incorrectly. Li yong-jun[4] improved the topology inference algorithm based on hamming distance, and reduced the probability of wrongness in multicast topology inference.

In unicast networks, the measurement techniques in topology inference are different with common measurement techniques. There are two popular measurement methods in topology inference of unicast network, one is “back to back”packets pair probe [5, 6], and the other is “sandwich” probe [7].

“Back to back”packets pair could probe one way delay and end to end loss; correlation could be calculated based on one way delay or end to end loss. When measuring one way delay, time synchronization was needed between nodes, while the end to end loss is only suit for networks of highly loaded [6]. “Sandwich” could probe the queuing delay, and topology could be inferred based on queuing delay, but it is only suit for networks of lightly loaded [6].

In order to reduce the limits of measurement method in topology inference, a 4-packets train measurement method was proposed, which could probe end to end delay variation[8] and end to end loss. When measuring end to end delay variation, no time synchronization was needed. A topology inference algorithm based on end to end delay variation and end to end loss was put forward and validated theoretically. Compared with “back to back”packets pair probe and “sandwich” probe, topology inference algorithm based on 4-packets train measurement method could suit for networks of lightly loaded, moderately loaded and highly loaded, and it had higher veracity.
2.4 4-packets Train Measurement

The 4-packets train is defined as below.

a) 4-packets train is composed of double packets pairs. We use \((Y_2, X_2, Y_1, X_1)\) denote one 4-packets train, the packet \(X_i\) and packet \(Y_i\) are packets pair, packet \(X_2\) and packet \(Y_2\) are packets pair.

b) The four packets in one 4-packets train have the same size, for example we set their size 50B;

c) Packet \(X_i\) and packet \(X_j\) have the same destination, packet \(Y_i\) and packet \(Y_j\) have the same destination which is different with destination of \(X_i\);

d) There is stable interval between the double packets pairs in 4-packets train. The interval between packets of one packets pair is so small that the packets in common links have similar situations.

In 4-packets train, every packet has much information including the sequence number and the position number. The sequence number of 4-packets train begins at number 1 and incremented by every 4-packets train. In 4-packets train the position number is only 1 or 2, the first packets pair has position number of 1, and the second packets pair has position number of 2. Figure 1 is a sequence of 4-packets train.

When probing end to end delay variation and end to end loss by 4-packets train, a number of 4-packets train were sent from source node to destination node pairs, destination nodes record the receive times of probe packets, then end to end delay variation could be calculated by the intervals between packets in destination nodes and end to end loss could be calculated by the numbers of received packets and probed packets.

Figure 2 is a representative example of end to end delay variation probe by 4-packets train. The 4-packets train in figure 2 is \((Y_2, X_2, Y_1, X_1)\). In the 4-packets train, packets \(Y_i\) and \(Y_j\) have the same destination of node 3; packets \(X_i\) and \(X_j\) have the same destination of node 2. At source node the interval between packets \(X_i\) and \(X_j\) and the interval between packets \(Y_i\) and \(Y_j\) are same and stable. The interval between \(X_i\) and \(X_j\) is recalculated and the received packets number is counted at node 2. The interval between \(Y_i\) and \(Y_j\) is recalculated and the received packets number is counted at node 3 too. End to end delay variation could be calculated by old interval and new interval, which did not need time synchronization. The end to end loss could be calculated by the numbers of sent packets and received packet.
In order to prevent the packets influenced with each other, we restrict the intervals in one 4-packets train. Suppose the links that 4-packets train passed are \( L_1, L_2, \ldots, L_m \), and the bandwidths of these links are \( b_1, b_2, \ldots, b_m \), and suppose the size of packets in 4-packets train is \( s(p) \), then the interval between packets pairs in a 4-packets train must satisfied formula (1).

\[
\frac{s(p)}{T_i} < \min(b_i), (1 \leq i \leq n)
\]  

(1)

3. Correlation Calculation and Topology Inference Algorithm

3.1 Correlation Calculating by Delay Variation

Suppose the 4-packets train is \((y_2-x_2, y_1-x_1)\), the interval between packets pairs is \( T_i \), and the interval between packets in one packets pair is 0. Suppose the interval between 4-packets train is \( T \), the first 4-packets train is sent at time \( T_0 \) (\( T_0 \) could be 0), then the packets in the first 4-packets train are sent at times \( \{ T_0, T_0 + T, T_0 + 2T, \ldots \} \), the packets in the \( n^\text{th} \) 4-packets train are sent at times \( \{ T_n, T_n + T, T_n + 2T, \ldots \} + NT \).

Suppose the destination of packets \( x_1 \) and \( x_2 \) in 4-packets train is \( D_a \), the destination of packets \( y_1 \) and \( y_2 \) in 4-packets train is \( D_s \). Suppose the times of packets received at node \( D_i \) are \( T_i \), then \( T_i = \{ T_{a_i}, T_{a_{i1}}, T_{a_{i2}}, \ldots, T_{a_{in}}, T_{a_{i1}}, \ldots, T_{a_{in}}, T_{a_{i1}} \} \), \( T_{s_i}, T_{s_{i1}}, T_{s_{i2}}, \ldots \) denotes the received time of packets \( x_1 \) and \( x_2 \) of the \( i^\text{th} \) 4-packets train. If there is packet lost in a 4-packets train, the received times of packets in the 4-packets train are excluded. End to end delay variation calculated at node \( D_i \) of the first 4-packets is \( T_{dvx_1}, T_{dvx_2}, T_{dvx_3}, T_{dvx_4} \) could be calculated by formula (2).

\[
T_{dvx_i} = (T_{x_{i2}} - T_{x_{i1}}) - T_i
\]

(2)

The end to end delay variation calculated at node \( D_j \) of the \( n^\text{th} \) 4-packets train \( T_{dvyn}, T_{dvyn} \) could be calculated by formula (3).

\[
T_{dvyn} = (T_{y_{n2}} - T_{y_{n1}}) - T_i
\]

(3)

Figure 3 correlation calculation based on delay variation

Figure 3 is an example of correlation calculation based on end to end delay variation. In figure 3, the destinations pair of 4-packets train is \((i,j)\), suppose \( a(i,j) \) is father of leaf \( i \) and leaf \( j \), suppose \( y^{i\rightarrow} \) denotes the end to end delay variation from source \( S \) to leaf \( i \), and \( y^{j\rightarrow} \) denotes the end to end delay variation from source \( S \) to leaf \( j \). \( y^{i\leftarrow} \) denotes the delay variation of path \( (S \rightarrow a(i,j)) \), \( y^{j\leftarrow} \) denotes the
delay variation of path \((a(i,j)\rightarrow i)\) and \(J_{a(i,j)}^{m,n}\) denotes the delay variation of path \((a(i,j)\rightarrow j)\). We compute the covariance of \(Y_{a(i,j)}^{m,n}\) and \(Y_{a(i,j)}^{m,n}\).

Because the packets in different links are independent, 
\[
\text{Cov}(J_{a(i,j)}^{m,n}, J_{a(i,j)}^{m,n}) = 0, \text{Cov}(J_{a(i,j)}^{m,n}, J_{a(i,j)}^{m,n}) = 0, \text{Cov}(J_{a(i,j)}^{m,n}, J_{a(i,j)}^{m,n}) = 0.
\]
We could get the conclusion of formula (4)
\[
\text{Cov}(Y_{a(i,j)}^{m,n}, Y_{a(i,j)}^{m,n}) = \text{Cov}(J_{a(i,j)}^{m,n} + J_{a(i,j)}^{m,n}, J_{a(i,j)}^{m,n} + J_{a(i,j)}^{m,n}) = \text{Var}(J_{a(i,j)}^{m,n})
\]

Suppose the path \((S\rightarrow a(i,j))\) is composed of links \(L_1, L_2, \ldots, L_m\), and \(M_{a(i,j)}^{m,n}, M_{a(i,j)}^{m,n}, \ldots, M_{a(i,j)}^{m,n}\) denote the delay variations of links \(L_1, L_2, \ldots, L_m\). Because packets in different links are independent, then we could get formula (5).
\[
\text{Var}(J_{a(i,j)}^{m,n}) = \text{Var}(M_{a(i,j)}^{m,n} + M_{a(i,j)}^{m,n} + \ldots M_{a(i,j)}^{m,n})
\]
\[
= \text{Var}(M_{a(i,j)}^{m,n}) + \text{Var}(M_{a(i,j)}^{m,n}) + \ldots + \text{Var}(M_{a(i,j)}^{m,n})
\]

Based on formulas (4) and (5), we know that more common links of the destinations pair, bigger covariance of the delay variation.

We use \(J_{a(i,j)}\) denote the correlation between leaves \(i\) and \(j\), where \(J_{a(i,j)} = \text{Cov}(Y_{a(i,j)}^{m,n}, Y_{a(i,j)}^{m,n})\).

3.2 Correlation Calculating by Loss

End to end loss could be probed by 4-packets train measurement method, then the correlations based on end to end loss could be calculated. When calculated the correlations, we use success to replace loss (success=1-loss).

Figure 4 is an example of correlation calculation based on end to end loss. In figure 4, the destinations pair of 4-packets train is \((i,j)\), suppose \(a(i,j)\) is father of leaf \(i\) and leaf \(j\), suppose \(s_{i\rightarrow i}\) denotes the end to end success from source \(S\) to leaf \(i\) and \(s_{j\rightarrow j}\) denotes the end to end success from source \(S\) to leaf \(j\). \(r_{i\rightarrow j}\) denotes the success of path \((S\rightarrow a(i,j))\), \(p_{i\rightarrow i}\) denotes the success of path \((a(i,j)\rightarrow i)\) and \(p_{j\rightarrow j}\) denotes the success of path \((a(i,j)\rightarrow j)\).

Figure 4 correlation calculation based on loss

Suppose the number of 4-packets train that sent from \(S\) to \((i,j)\) is \(N_{i,j}\), then the number of packets pair is \(2N_{i,j}\). Suppose \(N_{i}\) is the number of probe packets received at leaf \(i\), \(N_{j}\) is the number of probe packets received at leaf \(j\), and \(N_{ij}\) is the number of packets pair received at node \(i\) and \(j\). We get
\[ S_{i,j}^{(a)} = \frac{N_a}{2N} (N_j \rightarrow \infty), \quad S_{i,j}^{(s)} = \frac{N_s}{2N} (N_j \rightarrow \infty) \quad \text{and} \quad S_{i,j}^{(i)} = \frac{N_i}{2N} (N_j \rightarrow \infty), \]
we can know that \[ S_{i,j}^{(a)} = p_{i,j}^{(a)} \cdot p_{i,j}^{(v)} \quad \text{and} \quad S_{i,j}^{(s)} = p_{i,j}^{(s)} \cdot p_{i,j}^{(v)} \quad \text{and} \quad S_{i,j}^{(i)} = p_{i,j}^{(i)} \cdot p_{i,j}^{(v)} \], so we could get formula (6)
\[ p_{i,j}^{(v)} = \frac{S_{i,j}^{(a)} \times S_{i,j}^{(s)}}{S_{i,j}^{(i)}} (N_j \rightarrow \infty) \quad (6) \]

We use \( p_{i,j}^{(v)} \) as correlation between leaves \( i \) and \( j \) based on loss. Suppose the path \((S \rightarrow a(i,j))\) is composed of links \( L_1, L_2, \ldots, L_n \), and \( k_1^{(a)}, k_1^{(v)}, \ldots, k_1^{(i)} \) denote the success of links \( L_1, L_2, \ldots, L_n \), we could get formula (7)
\[ p_{i,j}^{(v)} = k_1^{(a)} \times k_2^{(v)} \times \cdots \times k_n^{(i)} \quad (7) \]

For \( k_j^{(a)} \leq 1 \), based on formulas (6) and (7), we know that more common links between leaves \( i \) and \( j \), less success of \( p_{i,j}^{(v)} \). Topologies could be inferred based on \( p_{i,j}^{(v)} \), which had the same effect with “back to back” packets paris[4].

4. References
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