In order for the musicians in an NMP session to interact with one another in a natural way, THE END-TO-END DELAY MUST BE KEPT BELOW HUMAN PERCEPTION; 30msec is a widely recognized bound.

Research Network. This set-up is representative of mid-size networks, with all nodes being reachable through a limited number of hops. Here, we measured a round-trip time of (8825/9315/15064/794)μs over 11 hops.

The table summarizes our measurement results. A

Type	Network Buffer		Total Delay	Packet Loss Statistics		
	[packets]	[msec]	[msec]	mean	max.	dev.
LAN	0	0	10.7	0.060%	2.4%	0.173%
LAN	2	5.3	16.0	0.015%	1.6%	0.101%
WAN	6	16.0	26.7	0.689%	6.9%	1.254%
WAN	10	26.7	37.3	0.216%	3.8%	0.519%

Delay and packet loss in several scenarios.

LAN session can be set up with no additional network buffers, resulting in a total delay of 10.7msec and a mean packet loss ratio of 0.06% suitable for high audio quality. The loss rate is further reduced by adding a network de-jitter buffer with one audio packet at the client and one at the server, respectively. Adding this buffer increases total delay to 16msec but reduces the packet loss rate to 0.015%.

In the WAN session, a network de-jitter buffer of three packets at both the client and the server is sufficient to keep the packet loss ratio below 0.7%. To further improve audio quality, the de-jitter buffer is enlarged by four audio packets, or 10.66msec, in the second WAN scenario. Here, the total delay is 37.3msec, and the packet loss ratio is reduced to 0.216%.

Along with these statistics and evaluation, we also conducted subjective listening and usability tests with musicians in both scenarios. Their evaluations further confirmed the good objective results.

CONCLUSION

This work is a significant step toward the general usability of NMP, bringing it out of the laboratory and one research LAN to potentially multiple commercial-scale WANs. We have shown that NMP is not only possible but can satisfy the stringent delay bound of 30msec. With long-distance evaluation,

we confirmed that network delay affects NMP behavior, indicating many possibilities for further enhancement.

One aspect of future work is to investigate whether the absolute delay bound of 30msec might be relaxed, with musicians able to adapt to the introduced delay, along with the extent of that relaxation. Relaxing that bound will surely extend the application boundary toward greater coverage in NMP sessions. Another is error concealment and correction schemes that would help application developers deal with packet loss during transmission. Moreover, besides a purely technical perspective, user interface and user evaluation must be improved to prepare NMP for commercial launch and user acceptance. **C**

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