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Investigation of the effectiveness of introducing a few adaptive controllable nodes in complex systems to increase autonomy and synchronization.

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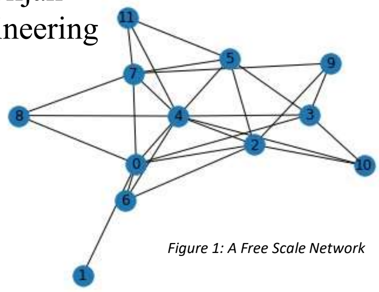

Figure 1: A Free Scale Network

A Network

A network[1] is made up of a range of **nodes**, which have associated weights, and **links** that connect a node to another. For this study we imagine these weights as demand. Examples of networks include the Electricity grid, Cellular connectivity and Water Supply. During the age of autonomy, networks mentioned face major problems regarding issues with security, unpredictable demand, limited supply and general fault management.

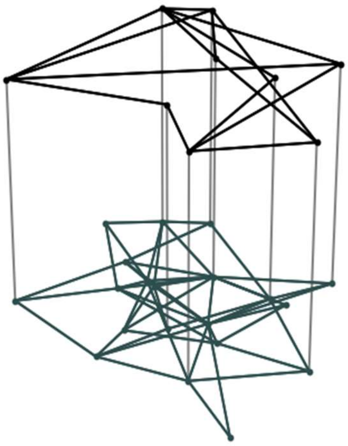
Figure 3: An Adaptive Network System: An Adaptive Layer is mapped on top of the existing Backbone Layer

What is an adaptive network, and why do we need it?

To cope with **dynamic** changes and faults in networks, an **adaptive network system**[2] can adjust its behaviour and structure without compromising the network performance. As a testing platform, we designed a **random adaptive layer generator** on top of the original backbone network, which tries to handle any state mismatch in demand between the nodes using a technique called **edge snapping**. We first tested the effectiveness of this system by replacing some nodes with **Lorenz nodes**, which generate periodic and extreme fluctuations that demand rapid and strong control actions. Figure 2 shows the model of the adaptive network

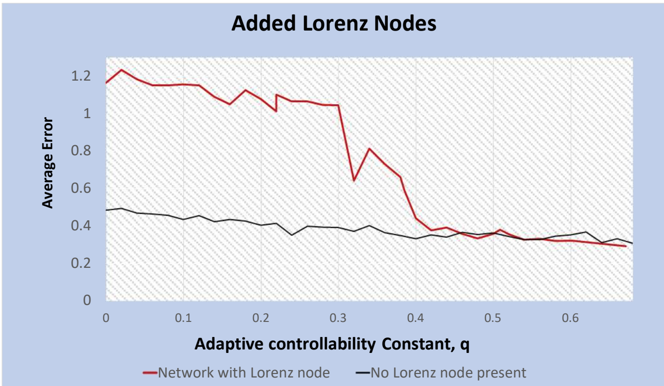

Figure 2. Comparing the error in the networks with increasing Adaptive Controllability with networks with a regular network and a network with a Lorenz node

As demonstrated by the data represented by the red line, a single Lorenz node adds almost twice the error in the network. But with a high enough controllability constant, the error can be brought down to **negligible** amount, which are similar to the results seen when no Lorenz nodes are added. Hence showcasing how adaptive networks can handle sudden high surges in demand.

Adaptive Synchronisation with selective adaptive nodes

Given the high cost and time required to build a fully adaptive network layer over an existing backbone network, this research opted for a different approach. It randomly placed adaptive nodes within the network, with only a select few having the ability to **create and destroy links**, to achieve synchronisation.

Figure 4 illustrates the modifications made to the adaptive network mapper, including the addition of various parameters to generate the desired outcome. Initially, an adaptive network was established with an adaptive node positioned over each backbone node, all of which were **interconnected**. This configuration was modified to include only a **select few nodes** to be adaptive. The final iteration of this model, gave us a **lower average degree** in the adaptive network.

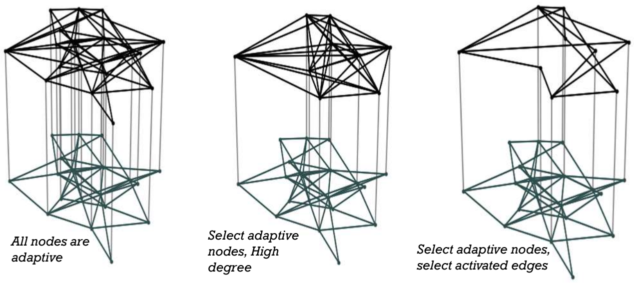

Figure 4: Developing a strategic, selective adaptive network system

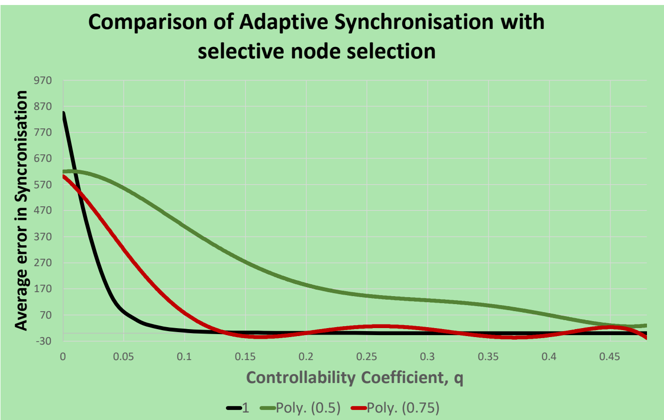

Figure 5: Showcasing the reduction in error using an adaptive network system

Results

Figure 5 illustrates the statistic model achieved at the testing of our selective constrained adaptive network model. The black line showcases the reduction in synchronization error when the adaptive network covers all the nodes. It can be seen with, even just 50% adaptive coverage, we can achieve a **similar** reduction with a **high controllability** coefficient! This gives us incredible insights into how upgrades in the global network systems can be planned and optimised.

Next Steps

This study chose to develop a model that had a random adaptive node selection, meaning that adaptive nodes were randomly allocated across the network. A more optimised way would be to find a more **strategic manner**, as this could reduce a lot of **noise**. This could be achieved by testing different node allocations on the same network and comparing the results. Insights from this could further improve the accuracy of the statistical model obtained in Figure 5 and shed light on **better arrangement patterns**

Acknowledgements & References

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1) Barabási, Albert-László, and Márton Pósfai. *Network Science*. Cambridge University Press, 2016.
2) Corso, Alessandra, et al. "Synchronizing Network Systems in the Presence of Limited Resources via Edge Snapping." Chaos: An Interdisciplinary Journal of Nonlinear Science, vol. 33, no. 1, Jan. 2023, p. 013123. DOI.org (Crossref), https://doi.org/10.1063/5.0093560.