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PR Mobile and Wireless Systems
Problems part 5

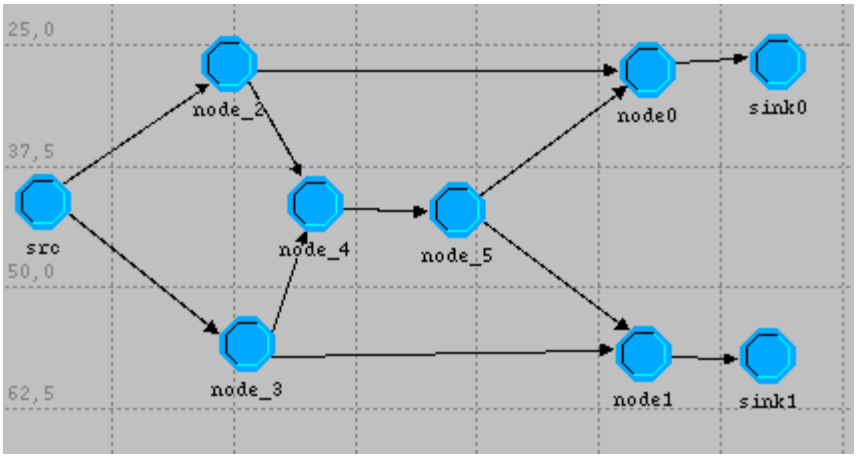
The following set of problems will show you how network coding can improve the throughput of a given network.

1. **Some questions concerning OPNET.**

   (a) When creating a new statistic for a node (and in the 'Choose individual DES statistics' dialog), it is possible to select a 'Capture mode'. What parameters can be selected and what is their purpose?

   (b) In the view results window several filters can be selected (e.g. as is, probability density, average, etc.). Describe each of them in one sentence!

2. **Measuring the throughput of a given network.**
   We want to simulate a network with one source and two sinks, where all traffic produced by the source should be sent to both sinks. We can then measure the traffic arriving at the sinks and thus get the throughput of the network. The network topology used is the following:



   To create that network topology, you have to define the following models:

   - A packet format containing only one data field.
   - A simplex point-to-point link model that is able to forward that packet format.

- Another simplex link model with a very high data rate such that no restriction having influence to any measures occur. That type of link is used e.g. between node0 and sink0.
- A source node generating data with a given data rate and sending it to all connected links. It should contain several transmitters (e.g. eight). It should be configureable to distribute the data to the transmitters used. If n transmitters are connected to a link and the data rate is d bit/sec, each link should e.g. get $\frac{d}{n}$ bit/sec. Another possibility would be that all transmitters get all the data generated. Transmitters that are not connected should not be used!
- A model for simple repeater nodes. They have several receivers and transmitters and can be configured to forward the data of one or more receivers to all its transmitters. If more receivers are enabled, all received packets should be sent one by one.
- A sink node that has several receivers (e.g. eight), destroys all packets it receives and measures the overall datarate in bit/sec.

All links are of the specified type with a specific restricted data rate except the links adjacent to the sinks. This is because node0 and sink0 has to be seen as one node but we don't want to create another node type containing the whole functionality of sink and repeater, especially in further examples.

For some of the node models you will probably have to create corresponding process models to implement its functionality. For example in the sink node you will have to create one node to serialize all inputs and one sink node collecting self defined data. For that purpose create your own process model, and never save any changes to the default model of OPNET (allways be sure to save your changes only in your own user directory).

First, try to think what the data rate of the network could be (try to justify). Don't forget that both sinks should get all the data created by the source (simultanously)! Then simulate the network and compare the result with your theoretical values. You should use different data rates at the source (use the 'Inputs' section of the 'Configure/Run DES' dialog).

3. Some theoretical aspects of network coding.
Try to answer the following questions briefly (not too much detail!) by using the internet or any other source (be sure that you fully understand your answer).

(a) What is a 'Network flow' and for which purposes it is used?

(b) Explain the 'Maximum flow problem'!

(c) How can the 'Max-flow min-cut theorem' be visualized using our example network?

4. Improving the throughput of the network using network coding.
When using network coding, the sink and the source nodes stay the same. We again want to transmit all the data from the source to each sink in the network (multicast scenario). The intermediate nodes, however, behave completely different. They don't forward packets unchanged. Instead, if they receive packets from

several receivers at the same time (we will have to define, what 'in the same time' means), they will combine them in some way (we will use XOR) and send the result to all transmitters.

Now we modify our example network using a simple network coding strategy. The source distributes the generated data on the two links such that each link gets exactly half the amount of all generated data. Node4 simply XORs all the data of all receivers and send it to its transmitters. The two nodes at the sinks (node0 and node1) have to use a correct decoding stategy to be able to send all the data to its sink. We define 'in the same time' a little bit different than usual. It is obvious that each node should receive a packet every time the source node generates one (on each input that is connected). Thus, we always wait until we have received a packet for each connected receiver and then generate the output of the node and send it to the transmitters.

You should now do the following tasks:

(a) Find a decoding strategy to restore all the data from the source.

(b) Estimate the throughput of the network. Justify your estimation!

(c) Create a new node model for the decoding nodes (node0 and node1) and insert it into the network (create a new scenario!).

(d) Simulate the new network and compare the result to your estimation!