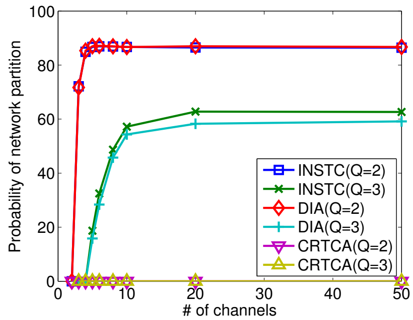

Fig. 4. Probability of network partition vs. # of channels

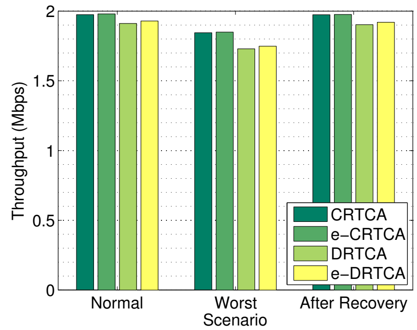

Fig. 5. The throughput of our approaches ($C = 20$ channels, $Q = 2$ radios, $F = 2$ flows, $B = 2$ Mbps)

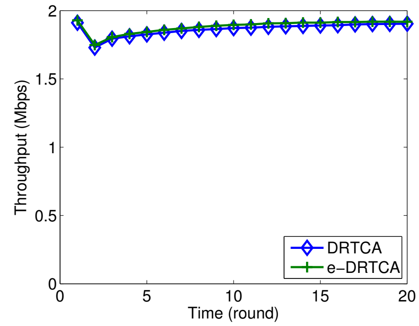

Fig. 6. The throughput of the distributed approaches ($C = 20$, $Q = 2$, $F = 2$, $B = 2$)

e-CRTCA, CRTCA, e-DRTCA and DRTCA. CRTCA and DRTCA use the default channel selection rule, while e-CRTCA and e-DRTCA use the enhanced channel selection rule. For comparison, we implement two interference-aware approaches, INSTC [14] and DIA. INSTC is a centralized interference-aware approach where the channels are assigned in the descending order of the potential interference index. DIA is a distributed interference-aware approach obtained by disabling the robustness test in DRTCA, so that the assigned channel leads to minimum interference. Both approaches can be slightly modified to satisfy the robustness constraint, i.e., all nodes reserve one channel as a backup channel and then find the interference-minimum assignment using the remaining channels. The robust versions of INSTC and DIA are denoted by INSTC-backup and DIA-backup, respectively.

B. Simulation Results on Robustness

To measure robustness, we show the *probability of network partition*; i.e., the probability that the channel assignment is not robust (the network is partitioned when a channel is reclaimed by the primary user). Figure 4 compares CRTCA with other two approaches INSTC and DIA by averaging over $10,000$ randomly generated topologies, as the number of channels and the number of radios ($Q = 2$ or $Q = 3$) change. As shown in the figure, the probability of network partition in CRTCA is 0 since our algorithm is designed to satisfy the robustness constraint.

For INSTC and DIA, when each node has two radios ($Q = 2$), there is no network partition if the number of channels is two. This is because each node tunes its radios to the same two channels, and thus each pair of neighboring nodes can still communicate when either of the two channels is reclaimed by the primary user. If the number of channels is more than two, the probability of network partition increases sharply, but stays flat as the number of channels is more than 20. This is because both INSTC and DIA are unaware of the robustness constraint. Each node can only use two channels at one time and it has to match the channels used by its neighbors. Then, many channels are not used, and providing more available channels does not help improve the robustness.

Using three radios ($Q = 3$) can reduce the probability of network partition compared to using two radios ($Q = 2$). With more radios, each node can use more channels at the same time. This reduces the probability of network partition when a primary user appears. However, the probability of network partition is still very high compared to CRTCA which has no network partition.

From this experiment, we can see that having more available channels does not increase the robustness. Although adding more radios can increase the robustness, it has high cost due to the hardware cost of extra radios.

Note that other robust approaches such as DRTCA, INSTC-backup, and DIA-backup, also do not have network partition if only one channel is reclaimed by the primary user. We omit their plots in Figure 4 due to space limit.

C. Simulation Results on Network Performance

To measure the network performance, we inject several constant bit rate flows (F) into the network. The source and the destination are picked randomly. Each flow follows the shortest path from the source to the destination. If a node has multiple radios connected to the next node in the path, it dynamically forwards the packet using the channel that is least interfered by other transmissions.

To measure the network performance, we measure the *normal throughput* and the *worst throughput*. The normal throughput denotes the throughput when all channels are available; i.e., no primary user appearance. The worst throughput is the least among different cases when a primary user appears at different channels. In the following experiments, each flow is generated at rate 1Mbps. The bandwidth (the maximum transmission rate per channel) is BMbps.

1) Evaluation of Our Approaches: Figure 5 compares four versions of our approaches, CRTCA, e-CRTCA, DRTCA and e-DRTCA, in terms of the normal throughput, the worst throughput and the throughput after recovery from the worst scenario. The worst scenario corresponds to the scenario when the worst throughput is achieved. Suppose the channel that is reclaimed by the primary user in the worst scenario is c. For recovery, centralized approaches can simply re-run the channel assignment process with reduced number of available channels except c. In distributed approaches, only the link operating on channel c is assigned another available channel following the channel selection rule. The assignment should also satisfy the robustness constraint.