6 Results

To demonstrate the general effect on an MRC when robots create altruistic relationships, a simulated task fulfillment experiment was conducted in which 500 tasks were randomly created within a 6.4x6.4 m 2D workspace as shown in Fig. (1). Each task was randomly assigned to be within the task set of one of 8 robots operating in the space. After each of the 500 tasks are assigned, robots auction them off to all robots using an assumed wireless communication system. Robots will bid if they have sufficiently large altruism towards the auctioneer. The order of auctioning is random.

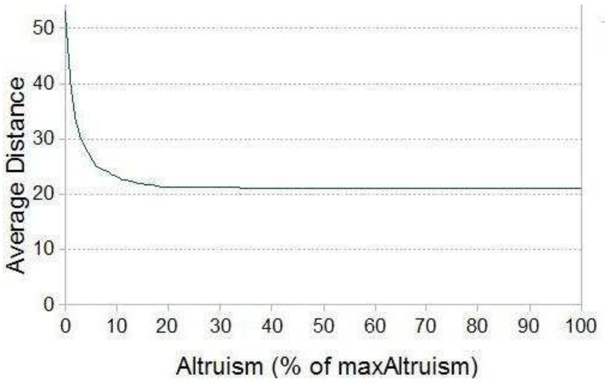

Fig. 2. Potential effects of increased altruism within an MRC

For each run of the experiment, robots had fixed but equal values of altruism. Between experiments, the altruism was incremented by 1% up to 20%, then incremented by 10%. In Fig. (2), the average robot path cost in meters is plotted for these values of altruism. Note that the values for altruism are normalized with respect to the percentage of the maximum value defined as the greatest distance between two points in the workspace (i.e. the length of the diagonal connecting opposite corners). The path costs show a dramatic decrease when compared with the case with no altruism. The cost plateaus where additional tasks typically won't cost a robot more than 20% of the largest distance a task point can occur on path cost for the given workspace. This can be observed in Fig. (1) as well, where in (a) no altruism results in paths that cross one another and the entire environment. However, in (c) where 100% altruism is used, paths are more localized and the personal cost functions decrease to the effect that the global cost function is also minimized.

To demonstrate the effects of the control law, consider the case where two robots start with random values for altruism with respect to each other (e.g. 0%, 18%). As shown in Fig. 3(a), the altruism between the two robots first converges and then grows with time (i.e. as new tasks are auctioned). It can be noted that the rising slope calculated from Fig. 3(a) is 1/16 which matches the expected value of $K\epsilon = (0.25)(0.25)$.

When robots are acting selfishly, the controller invoked by the altruistic robot is stable, (see Fig.3(b)). The altruism towards such selfish robots reaches equilibrium at the point ϵ greater than 0. Hence, the altruistic robot is still protected against selfish robots. Note that increasing the gain K increases the speed of convergence. In (c) and (d), cases where the altruism of other robots are estimated using equation (13) are presented. In (c), robot 1 has altruism fixed at 100%. Robot 2's altruism towards 1 starts at 100% and converges to the maximum bid used by robot 1. In (d), robot 1 has altruism fixed at 0, it can be seen that robot 2's altruism converges towards ϵ.

7 Conclusions and Future Work

This paper presented the idea of a Multi-Robot Community in which several robots sharing a common workspace are attempting to complete their individual tasks. It was shown that altruistic actions, where robots assist with each other's tasks, can lead to decreased path costs for individual robots.

While a controller was presented that can set altruism such that altruistic relationships can evolve between two altruistic robots and still protect against selfish robots, the real contribution comes from the idea of analyzing the stability of altruism as a linear time-invariant system. Future controllers can be designed and analyzed in a similar fashion.

Considerable work is still required, especially to resolve the assumptions listed above. In the future it is hoped that better estimation of another robot's altruism can be achieved, selfish robots that have variable values for alpha are addressed (e.g. gaming robots), situations with uneven task distribution are considered (5 tasks for one robot 100 for another), and practical implementation and experimentation may occur.

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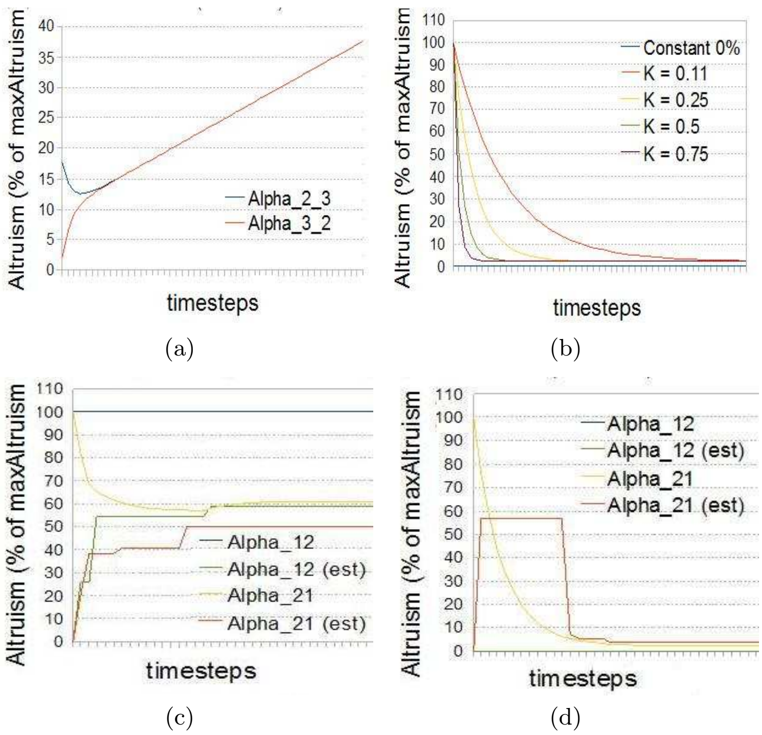

Fig. 3. Stability of altruism within an MRC. In (a), both robots use the altruistic controller but with different initial values (0% and 18%). In (b), only one robot uses the controller while the other robot maintains a fixed value of 0. In (c) and (d), the altruism must be estimated by robots.

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