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Appendix: BitTorrent Nash Equilibrium

In the following we use the notation introduced in Table 1 and the results from Sections 2.2 and 2.3.

In order to show that *BitTorrent is not a Nash equilibrium* (NE), we consider a swarm with $N-1$ BitTorrent (BT) peers and assume that one peer using the Birds protocol enters this swarm.

In this setup the expected number of games won by the BT clients against higher and lower classes do not change. On the other hand, for the Birds client only the formula for the expected number of games won against the peers from the lower classes changes to $E_B^r[B \to c]' = N_B/N_r$, which is the same as for the BT clients.

Now, we consider the class C where the peer using the Birds protocol is located. The expected values of the number of games that the peers win due to reciprocation from other peers in this class will be $E_B^r[C-c]' = U_r - K$ for Birds and

$$\begin{aligned} E^r[C \to c]' &= \frac{N_{C'} - U_r}{N_{C'}}(U_r - K - E[A \to c]) \\ &\quad + \frac{U_r}{N_{C'}}(U_r - E[A \to c] - K') \\ &= U_r - K - E[A \to c] - \frac{U_r}{N_{C'}}(K + K') \end{aligned}$$

for the BT clients, where $N_{C'} = N_C - 1$, and $K' = 1 - \left((1 - E[A \to c])(1 - \frac{1}{U_r})\right)^{U_r - 1}$, which leads us to the fact that

$$E_B[C \to c]' > E[C \to c]'.$$

Regarding the 'free game wins', the formulae change to

$$E_B[C \to c]' = \frac{N_{C'}}{N_C}(N_C - E^r[C \to c]')/N_r,$$

$$E[C \to c]' = E_B[C \to c]' + \frac{N_C - E_B^r[C \to c]'}{N_C N_r},$$

which says that $E[C \to c]' > E_B[C \to c]'$; however,

$$E_B^r[C \to c]' + E_B^r[C \to c]' > E^r[C \to c]' + E[C \to c]'$$

holds. Thus, the peer using the Birds protocol, on average, wins more games than any of the BT clients, proving that BT is not a NE.

Now we show that *it is a NE when all peers in the swarm follow the Birds protocol*.

We assume that there are $N-1$ peers following the Birds protocol and one peer using the BT protocol enters this swarm. We give a formal proof for the case when this new peer uses BT; the other three cases (regarding class-based reciprocation) can be proved in the similar way.

First, we consider the games where peers get reciprocation. Neither the Birds peers nor the BT peer get anything from the higher and lower classes. For that particular class C, where the BT peer is located we have

$$\begin{aligned} E_B^r[C \to c]'' &= \frac{N_{C'} - U_r}{N_{C'}}U_r + \frac{U_r}{N_{C'}}(U_r - E[A \to c]) \\ &= U_r - \frac{U_r}{N_{C'}}E[A \to c], \end{aligned}$$

where $N_{C'}$ is the number of Birds in class C, i.e. $N_{C'} = N_C - 1$. Moreover, we have $E^r[C \to c]'' = U_r - E[A \to c]$; from here it is easy to see that $E_B^r[C \to c]'' > E^r[C \to c]''$.

'Free game wins' remain the same. The expressions for the same class become

$$E[C \to c]'' = \frac{N_{C'}}{N_C} \times \frac{N_{C'} - E_B^r[C \to c]}{N - U_r - 1},$$

and

$$E_B[C \to c]'' = E[C \to c]'' + \frac{N_{C'} - E^r[C \to c]}{N_{C'}(N - U_r - 1)},$$

Thus we conclude that $E_B[C \to c]'' > E[C \to c]''$ which completes our proof that Birds is a NE.