Security and Privacy in Wireless Networks

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A Tutorial on Game Theory for Wireless Networks

Appendix B

Security and Cooperation in Wireless Networks

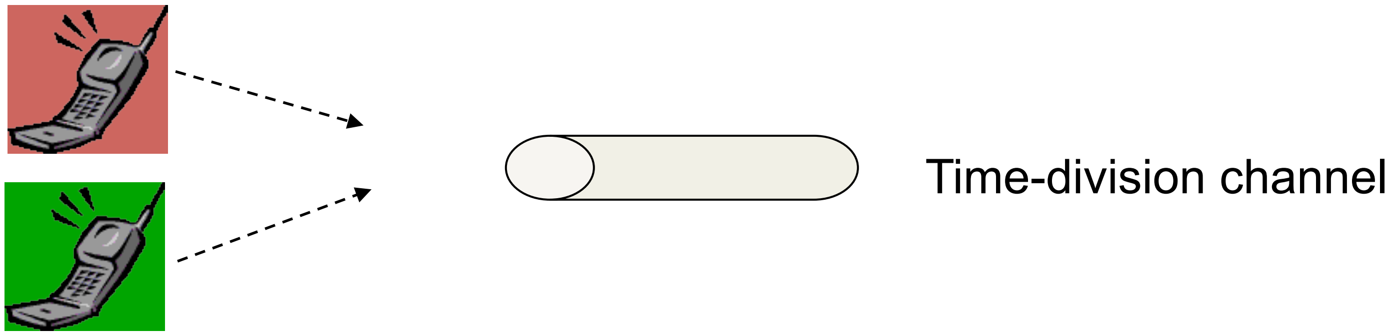
secowinet.epfl.ch

static games, dynamic games, repeated games, strict and weak dominance, Nash equilibrium, Pareto optimality, and subgame perfection

Chapter outline

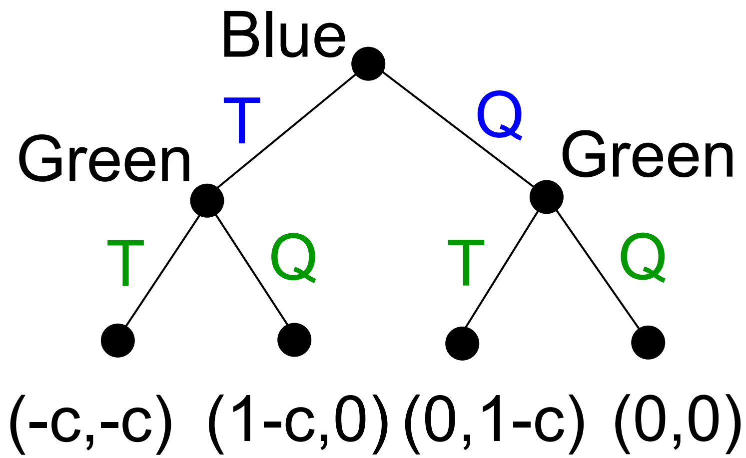
Extensive-form games

- usually to model sequential decisions
- game represented by a tree
- Example 3 modified: the **Sequential** Multiple Access game: Blue plays first, then Green plays.



Reward for successful transmission: 1

Cost of transmission: c
(0 < c << 1)

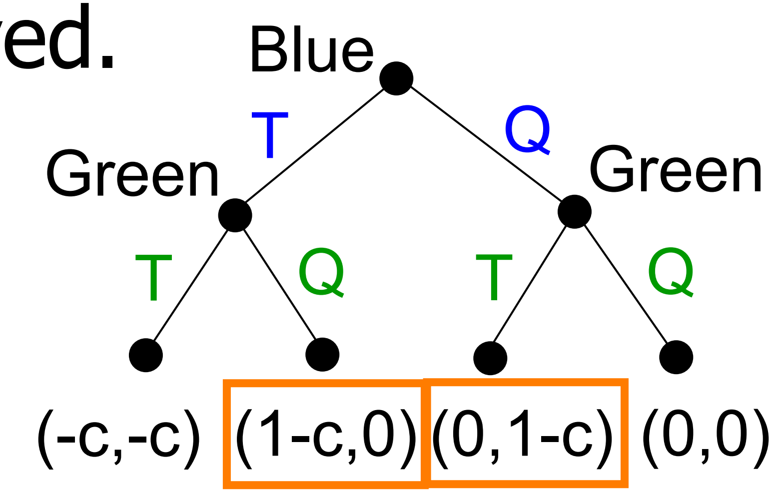


Strategies in dynamic games

- The strategy defines the moves for a player for every node in the game, even for those nodes that are not reached if the strategy is played.

strategies for Blue:
T, Q

strategies for Green:
TT, TQ, QT and QQ



TQ means that player p2 transmits if p1 transmits and remains quiet if p1 remains quiet.

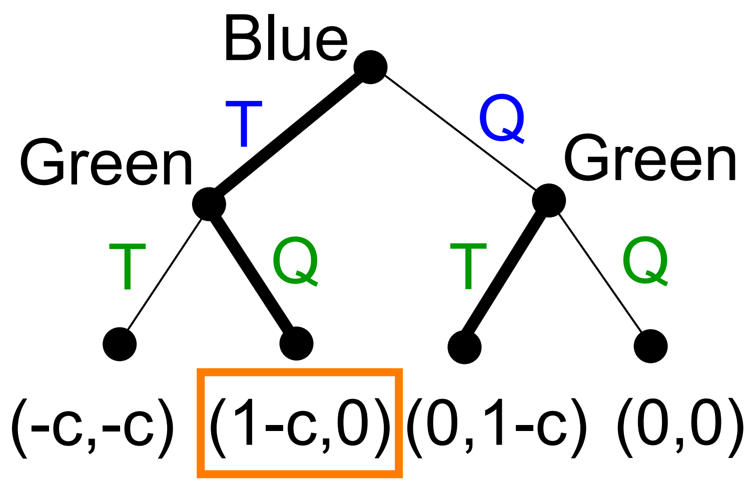
Extensive to Normal form

Blue vs. Green	TT	TQ	QT	QQ
T	(-c,-c)	(-c,-c)	(1-c,0)	(1-c,0)
Q	(0,1-c)	(0,0)	(0,1-c)	(0,0)

Backward induction

- Solve the game by reducing from the final stage
- Eliminates Nash equilibria that are *increadible threats*

Incredible threat: (Q, TT)



Backward induction solution: h={T, Q}

Subgame perfection

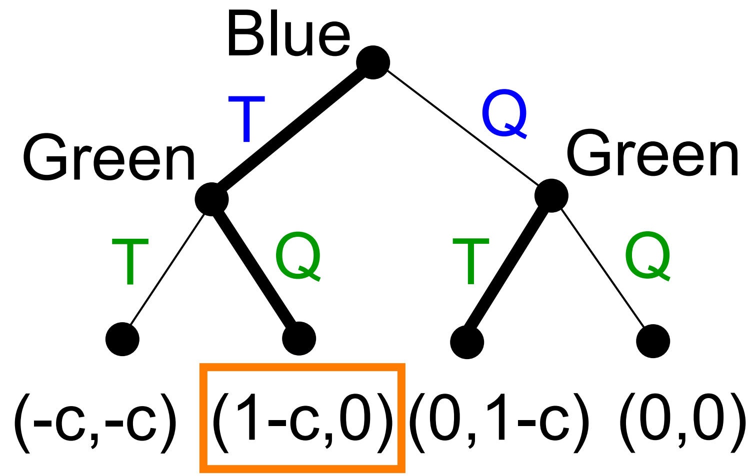
- Extends the notion of Nash equilibrium

One-deviation property: A strategy s_i conforms to the *one-deviation property* if there does not exist any node of the tree, in which a player *i* can gain by deviating from s_i and apply it otherwise.

Subgame perfect equilibrium: A strategy profile *s* constitutes a subgame perfect equilibrium if the one-deviation property holds for every strategy s_i in *s*.

Finding subgame perfect equilibria using backward induction

Subgame perfect equilibria:
(T, QT) and (T, QQ)



Stackelberg games have one leader and one or several followers

Chapter outline

B.1 Introduction

B.2 Static games

B.3 Dynamic games

B.4 Repeated games

Repeated games

- repeated interaction between the players (in stages)
- move: decision in one interaction
- strategy: defines how to choose the next move, given the previous moves
- history: the ordered set of moves in previous stages
  - most prominent games are history-1 games (players consider only the previous stage)
- initial move: the first move with no history
- finite-horizon vs. infinite-horizon games
- stages denoted by t (or k)

Utilities: Objectives in the repeated game

- finite-horizon vs. infinite-horizon games
- myopic vs. long-sighted repeated game

myopic: $\overline{u}_i = u_i(t+1)$

long-sighted finite: $\overline{u}_i = \sum_{t=0}^{T} u_i(t)$

long-sighted infinite: $\overline{u}_i = \sum_{t=0}^{\infty} u_i(t)$

payoff with discounting: $\overline{u}_i = \sum_{t=0}^{\infty} u_i(t) \cdot \omega^t$

$0 < \omega \leq 1$ is the discounting factor

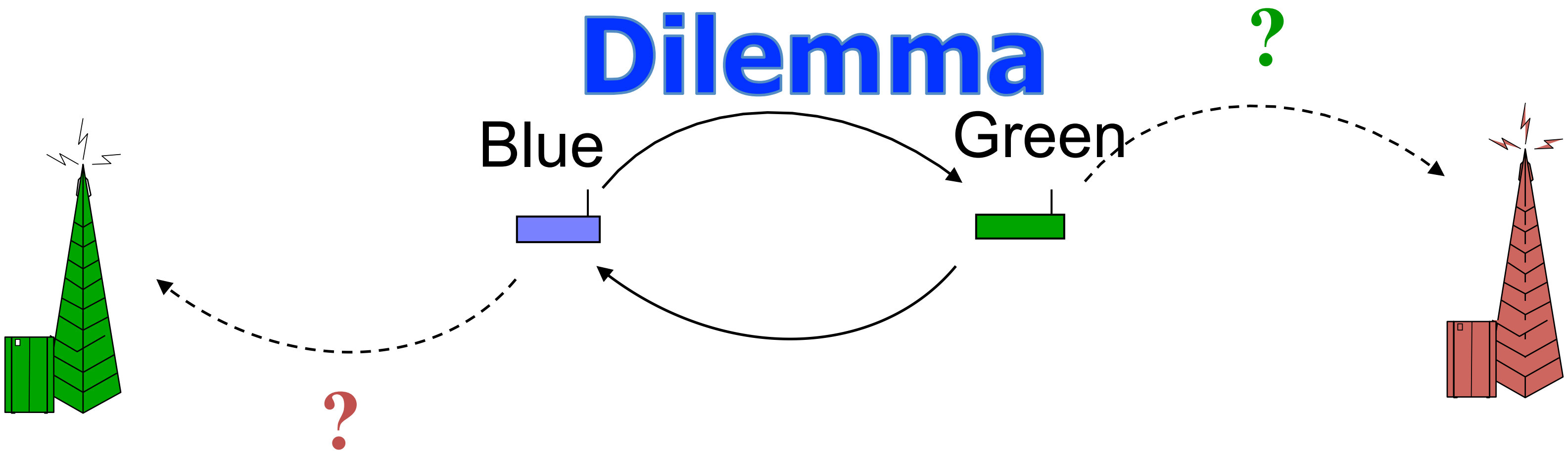
Strategies in the repeated game

- usually, history-1 strategies, based on different inputs:
  – others' behavior: $m_i(t+1) = s_i\left[m_{-i}(t)\right]$
  – others' and own behavior: $m_i(t+1) = s_i\left[m_i(t), m_{-i}(t)\right]$
  – payoff: $m_i(t+1) = s_i\left[u_i(t)\right]$

Example strategies in the Forwarder's Dilemma:

Blue (t)	initial move	F	D	strategy name
Green (t+1)	F	F	F	AllC
	F	F	D	Tit-For-Tat (TFT)
	D	D	D	AllD
	F	D	F	Anti-TFT

The Repeated Forwarder's Dilemma



Blue \ Green	Forward	Drop
Forward	(1-c, 1-c)	(-c, 1)
Drop	(1, -c)	(0, 0)

stage payoff

Analysis of the Repeated Forwarder's Dilemma (1/3)

infinite game with discounting: $\bar{u}_i = \sum_{t=0}^{\infty} u_i(t) \cdot \omega^t$

Blue strategy	Green strategy	Blue payoff	Green payoff
AllD	AllD	0	0
AllD	TFT	1	-c
AllD	AllC	1/(1-ω)	-c/(1-ω)
AllC	AllC	(1-c)/(1-ω)	(1-c)/(1-ω)
AllC	TFT	(1-c)/(1-ω)	(1-c)/(1-ω)
TFT	TFT	(1-c)/(1-ω)	(1-c)/(1-ω)

Analysis of the Repeated Forwarder's Dilemma

Blue strategy	Green strategy	Blue payoff	Green payoff
AllD	AllD	0	0
AllD	TFT	1	-c
AllD	AllC	$1/(1-\omega)$	$-c/(1-\omega)$
AllC	AllC	$(1-c)/(1-\omega)$	$(1-c)/(1-\omega)$
AllC	TFT	$(1-c)/(1-\omega)$	$(1-c)/(1-\omega)$
TFT	TFT	$(1-c)/(1-\omega)$	$(1-c)/(1-\omega)$

- AllC receives a high payoff with itself and TFT, but
- AllD exploits AllC
- AllD performs poor with itself
- TFT performs well with AllC and itself, and
- TFT retaliates the defection of AllD

TFT is the best strategy if ω is high !

Analysis of the Repeated Forwarder's Dilemma

Blue strategy	Green strategy	Blue payoff	Green payoff
AllD	AllD	0	0
TFT	TFT	$(1-c)/(1-\omega)$	$(1-c)/(1-\omega)$

Theorem: In the Repeated Forwarder's Dilemma, if both players play AllD, it is a Nash equilibrium.

Theorem: In the Repeated Forwarder's Dilemma, both players playing TFT is a Nash equilibrium as well.

The Nash equilibrium s_{Blue} = TFT and s_{Green} = TFT is Pareto-optimal (but s_{Blue} = AllD and s_{Green} = AllD is not) !

Experiment: Tournament by Axelrod, 1984

- any strategy can be submitted (history-X)
- strategies play the Repeated Prisoner's Dilemma (Repeated Forwarder's Dilemma) in pairs
- number of rounds is finite but unknown

↓

- TFT was the winner
- second round: TFT was the winner again

R. Axelrod *The Evolution of Cooperation*
Basic Books, 1984

Discussion on game theory

- Rationality
- Payoff function and cost
- Pricing and mechanism design (to promote desirable solutions)
- Infinite-horizon games and discounting
- Reputation
- Cooperative games
- Imperfect / incomplete information

Conclusions

- Game theory can help modeling greedy behavior in wireless networks
- Discipline still in its infancy
- Alternative solutions
  - Ignore the problem
  - Build protocols in tamper-resistant hardware