Journal of Automata, Languages and Combinatorics **11** (2006) 1, 23–58

TIMED EXTENSIONS OF π CALCULUS [1,2]

JING CHEN

Capability Lab., CIeNET Technologies Co., 11F, Jin Yun Building A
No. 43 of Xi Zhi Men North Street, Hai Dian District, Beijing 100044, P. R. China
and
Laboratoire d'Informatique Fondamentale d'Orléans, Université d'Orléans
Rue Léonard de Vinci, B.P. 6759, 45067 Orléans Cedex 2, France
e-mail: jchen@cienet.com.cn, jing000@gmail.com

ABSTRACT

The purpose of this paper is to incorporate a notion of time in π calculus. Timed π – the timed extensions of π calculus – are calculi for timed mobile processes, which can model not only evolving systems but also systems with real-time behaviors. We first present such a calculus with the assumption that actions consume no time; a theory of timed bisimulations is studied, and it is shown that the important algebraic properties of π calculus are preserved in the timed setup; a notion of maximal progress with respect to time is a feature of this calculus, arising due to the assumption extension. We also present briefly a second timed π, under the opposite assumption that every action should consume some time; this calculus is simpler in the sense that its set of operators is of the same 'size' as for standard π, and it makes no assumption of maximal progress, or urgency of τ-actions. The expressive power and axiomatizability for both calculi are discussed, and illustrated with some examples.

Keywords: Process algebra, bisimulation, mobility, real-time, synchronization

1. Introduction

In recent research on concurrency, real time has been studied intensively since time is a crucial factor in many protocols and controlling systems. Systems such as wireless/wired controllers, mobile equipments and protocols may not work correctly without considering time: the result of a computation finished after the deadline may be useless or even lead to fatal error. Critical actions happening at slightly different time points could substantially change the behavior of the system: for instance, in Mobile IP [40], timing is indispensable for ensuring that mobile nodes are always connected to the network. Besides, security is also closely related to time: thus, in [15], by measuring the time the user's browser requires to perform certain operations, an attacker

[1]Full version of a submission presented at the *International Workshop on Security Analysis of Systems: Formalisms and Tools*, SASYFT 2004, (Orléans, France, June 21 – 22, 2004).

[2]Supported by National Science Foundation of China, and by **le_STUDIUM**, http://lestudium.cnrs-orleans.fr/, Orléans